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Monterey, California

THESIS

A STATISTICAL ANALYSIS OF SURFACE ESCORT
COST ESTIMATION

by

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This study investigates the relationship of the component weights of US Navy Surface Escort Ships and their corresponding costs of construction. The procedures of various US Navy agencies who conduct Surface Ship Costing are described, with emphasis upon the method followed by COMNAVSEASYSCOM, Washington D.C.. A statistical analysis is provided which focuses upon multiple linear regression techniques applied to the weight/cost relationship. Additionally, the research includes the investigation of non-weight explanatory variable contribution to the various regression models. The analysis concludes that linear relationships do exist between the variables. The statistical evidence provided suggests that linear regression provides equivalent results to non-linear logarithmic transformation of the dependent cost variable. Further, the analysis indicates that the inclusion of non-weight dummy variables, such as contract type for vessel construction, enhance models with strictly weight explanatory variables. The models developed herein lack the precision demanded of budgetary cost estimating. However, the equations will generate point estimates that may add credence to existing methods, especially within concept formulation or tradeoff studies.

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A Statistical Analysis of Surface
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ABSTRACT

This study investigates the relationship of the component weights of US Navy Surface Escort Ships and their corresponding costs of construction. The procedures of various US Navy agencies who conduct Surface Ship Costing are described, with emphasis upon the method followed by COMNAVSEASYSCOM, Washington D.C.. A statistical analysis is provided which focuses upon multiple linear regression techniques applied to the weight/cost relationship. Additionally, the research includes the investigation of non-weight explanatory variable contribution to the various regression models. The analysis concludes that linear relationships do exist between the variables. The statistical evidence provided suggests that linear regression provides equivalent results to non-linear logarithmic transformation of the dependent cost variable. Further, the analysis indicates that the inclusion of non-weight dummy variables, such as contract type for vessel construction, enhance models with strictly weight explanatory variables. The models developed herein lack the precision demanded of budgetary cost estimating. However, the equations will generate point estimates that may add credence to existing methods, especially within concept formulation or tradeoff studies.

TABLE OF CONTENTS

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I. INTRODUCTION

A. RESEARCH OBJECTIVE

Until recent times ship design engineers and program managers focused over a primary question of: "How will the ship, as a system, perform?" Recent media attention over cost-overruns and increasing budgetary pressures however, have added: "How much, as a system, will the ship **cost**?" Due to increasing concern over acquisition costs, the necessity of accuracy in ship cost estimating is of fundamental importance.

The ship weight estimate is a natural product of the design phase by naval architects. It has been found to be the most consistent physical property that the cost estimator is provided and considerable effort has been expended affirming the utility of the weight estimate.

The purpose of this research was to gain insight into the US Navy's methods of ship cost estimation and attest to the vitality of relationships used in cost modeling procedures.

B. RESEARCH QUESTIONS

Given the preceding objective, the primary research question follows: What method is used by the US Navy in its estimation of ship construction costs and will the relationships used by this model translate effectively into a multiple regression equation?

Additionally, the following subsidiary questions are felt relevant to the discussion:

- What are the problems associated with normalizing a population of escort ship data and transforming the data such that a proper linear fit is achieved?
- Does a statistical analysis of construction costs vs the inputs of the estimation model attest to the relationships currently being utilized?
- Given that a regression technique can be applied to the estimation model, will the derived equation provide usable estimations which substantiate or attest to the estimates provided by current procedures?
- What are possible alternatives to the primary estimation method and do those methods place equivalent emphasis upon the weight estimation to derive costs?

C. SCOPE, LIMITATIONS, AND ASSUMPTIONS

1. Scope

The research focused upon the procedures used by the COMNAVSEASYSCOM (NAVSEA) cost estimation branch, SEA 017. It is their output upon which Navy budgetary decisions are based. The basic effort was aimed at producing an accurate description of the quantitative costing methods for US Navy surface escort ships. Supportive of the basic effort was a similar description of the techniques of the NAVAL CENTER

FOR COST ANALYSIS and the DAVID TAYLOR NAVAL RESEARCH & DEVELOPMENT CENTER.

This thesis presents a summary of the actual process and the results achieved by the cited agencies. Additionally, this research develops an analytical technique which within a relevant range, could be applied as a benchmark check of future surface ship cost estimations.

2. Limitations

This study is limited to the accuracy of the data cited herein, within the above stated scope of the research. Further, more specific comments regarding the limitations of the data base and its proprietary nature are provided in the Analysis section of this research.

The thesis intent was not to assess the ability, nor the specific procedures used by the ship cost estimating departments of the Navy. The analytical procedures developed herein are in no way expected to achieve or replace the accuracies demanded of the NAVSEA budgetary input to the PPBS.

3. Assumptions

Throughout this thesis, the presumption has been made that referenced estimates were the best outputs from the data available at the time of the analysis. In addition, the cited computer outputs contained within the analysis section are assumed to be accurate within the limitations of the data.

D. RESEARCH METHODOLOGY

The methodology chosen was that of case by case investigation of the Navy's three primary agencies using surface ship cost estimation techniques. Personal interviews were made with those personnel directly responsible and documentation was obtained from those same sources. The data cited herein unless otherwise noted, is that of NAVSEA, extracted from their "Program Review System" reports and various other NAVSEA sources. Additional background research consisted of various publications and journals, and the literature base of the Defense Logistics Studies Information Exchange (DLSIE).

E. ORGANIZATION OF THE REPORT

Chapter II is an overview of the subject of ship cost estimating. The presentation will show that ship costing is a multi-faceted discipline, involving overlapping aspects of engineering, economics, business management, statistics and human resources. Additionally, this section will provide a frame of reference for the differing levels of US Navy cost estimate "quality" and the technical detail required of the varying levels.

Chapter III provides a description of the specific cost estimating technique utilized by the NAVSEA cost estimation branch (SEA 017). The discussion will show how these methods are applied to estimating modern escort construction costs. This chapter will continue to develop the frame of reference and terminology required of the cost estimating discipline. Chapter III concludes with highlights from the procedures used by the NAVAL CENTER FOR COST ANALYSIS (NCA) and the DAVID TAYLOR NAVAL SHIP RESEARCH and DEVELOPMENT CENTER (DTNSRC).

Chapter IV is the bulk of the research effort and statistically investigates the relationship between ship cost and ship weight estimates. This broad measure (weight versus cost) is the starting block to investigate the viability of the weight estimate in the specific subcategories that the cost estimator uses. The technique will then be applied to the component weights of the vessels, in order to ascertain whether or not the same relationship holds.

Chapter V summarizes the principal findings of the study and the conclusions reached. Practical recommendations are made and suggestions for further research are provided.

II. COST ESTIMATING, A BACKGROUND AND THEORETICAL REVIEW AS IT RELATES TO ESCORT CONSTRUCTION

A. INTRODUCTION

The purpose of this chapter is to provide an overall perspective of the subject of cost estimating, especially as it relates to ship construction cost. Further, this chapter provides the theoretical base upon which the research was conducted. The discussion begins by examining relevant concepts and terminology related to the topic.

B. DEFINITIONS AND CONCEPTS

1. End Costs

End costs are those which represent the full funding of all reasonable and expected costs through ship construction and post-delivery period (post shakedown availability, commonly referred to as PSA) [Ref. 1:p. 2-10]. End costs relate with the term "procurement costs". Other pertinent attributes of end costs are: (1) end costs are indexed for inflation, adjusting for ship building contracts stretching over several years, and (2) end costs include unanticipated funding requirements which could arise over the shipbuilding period.

2. Major Cost Category 211

The "costs" which form the primary basis of this research are those associated with Major Cost Category 211

(MCC 211). MCC 211 is that portion of the end cost estimate allocated specifically for the "Basic Construction" of the ship. In Chapter III, the discussion will show how the MCC 211 cost estimate is formed from the varying weight groups of the designed platform.

3. Types of Government Contracts

A broad understanding of the major types of contractual agreements existing between government and private industry is instrumental to the discussion of ship costing. As the ship progresses from concept to construction, the type of contract issued has definite impact upon the way the shipbuilder manages the contract. In essence, contracts are offers and the acceptance of those offers backed by legal considerations. Contract type therefore, does not directly impact the cost estimate itself but may provide great insight into the end cost as a function of the contractors' incentive for the completed vessel. This section briefly describes some of those vehicles.

Cost contract: A cost contract calls for the government to pay all allowable costs involved in executing a given research project. The contractor receives no fee. This type of contract establishes an estimate of the total costs as defined in the contract for purposes of (1) obligating current funds, and (2) establishing a ceiling beyond which the contractor cannot proceed (except at his own risk) without prior approval [Ref. 2:p. 4-23].

<u>Cost-sharing contract</u>: Under cost-sharing, the yard is reimbursed for an agreed portion of allowable costs, not to exceed an established ceiling without fee [Ref. 2].

<u>Cost-plus-fixed-fee contract</u>: The cost plus fixed fee contract is similar to the cost contract in that it provides for payment of all allowable costs as defined in the contract, and establishes an estimate of total cost [Ref. 2]. In addition, it provides for the payment of a fixed fee based primarily on the nature of work to be performed.

<u>Cost-plus-incentive-fee contract</u>: The cost plus an incentive fee contract is a cost reimbursement type agreement with provision for a fee. The fee is adjusted by formula in accordance with the relationship from which total allowable costs bear to target costs. Under this type of contract, there is initially negotiated a target cost, a target fee, a minimum and maximum fee, and a fee adjustment formula. Factors other than cost, including performance and progress, can also be used as a basis for contract incentive. [Ref. 2]

<u>Fixed-price-incentive contract</u>: The fixed price incentive contract includes a provision for the adjustment of profit and the establishment of the final contract price. The price is computed by a formula based on the relationship

which final negotiated total cost bears to target costs. Under this type of agreement, target cost, profit, price ceiling, and a formula for establishing final profit and price are negotiated prior to execution. [Ref. 2]

Firm-fixed-price contract: The firm fixed price contract provides for a price which is not subject to any adjustment by reason of the cost experience of the contractor in performance of the contract. This type of agreement, when appropriately applied, places maximum risk upon the contractor. Because the contractor assumes full responsibility, in the form of profit or loss for all costs under or over the firm fixed price, he has a maximum profit incentive of effective cost control and contract performance. The firm fixed price contract is suitable for use in procurements in which reasonably definitive design and performance specifications are known and fair and reasonable prices can be established at the outset. This type of contract is also suitable for level-of-effort work in which the contractor is compensated for expending his best effort at fulfilling program requirements. [Ref. 2]

C. SHIP DESIGN PROCESS

To gain an insight of how the ship design process and ship cost estimation relate, major areas of concern (from the perspective of NAVSEA) will be highlighted. There are three principal divisions in the NAVSEA ship design process;

(1) exploratory design
(2) acquisition design
(3) service life design

Since this study deals with early stage new ship cost estimating, only the exploratory and acquisition design phases are of concern. The four acquisition design phases are feasibility studies, preliminary design, contract design and detail design. Figure 2.1 indicates the order that the design process follows, starting from a statement of mission requirements from the customer (the Navy) and ending with a detail design [Ref. 2:p. 1-14].

Phase Event

Authorized at milestone	Ship Acquisition (design, development for operational use)	Ship Development (design/construction for research, test or evaluation)
Mission need Statement	-	-
Program initiation	Conceptual design and tradeoffs (feasibility)	Conceptual design and tradeoffs
I	Start preliminary design; preliminary contract design	Start preliminary design
II	Decision for lead ship design and construction	Contract design and decision to build
III	Design for follow on ships (detail)	Detail design

Figure 2.1
Ship Design / Development Milestones

Typically, these phases can be differentiated from each other by the increase in technical definition of the ship (i.e., a reduction in the technical uncertainty) as the design progresses from exploratory through to detail design. At any given stage in the ship's design, all of the ship systems will be defined to the same level of detail. Table 2.1 illustrates the increase in technical definition for a propulsion plant [Ref. 1:p. 4-2].

Level	Technical Definition
0	Whole ship
1	Propulsion plant
2	Propulsion units
3	Gas turbines
4	Engine starter system
5	Engine starter
.	...
.	...

Table 2.1
Example of Increasing Level of Technical Definition

In an R&D environment, the technical definition can increase to a level commensurate with detail design and yet the ship will remain in the exploratory studies phase.

D. NAVY COST ESTIMATION METHODS

Cost estimating efforts are found in every phase of the Navy's planning, programming, and budgeting cycle (PPBS) but the NAVSEA efforts are most influential upon the first two elements. The development of cost estimates for a particular program is the responsibility of the Principal Developing Activity (PDA). At the same time, independent cost estimates are produced by the Director of Navy Program Planning (OP-90). Also, there is a (DOD directed) Cost Analysis Improvement Group (CAIG) which conducts a complete review of both estimates and reports these results to the Defense Acquisitions Board (DAB). [Ref. 2:p. 4-53]

These agencies employ one of two general methodologies (sometimes both) to arrive at an estimate; (1) assimilate detailed estimates of the cost of work packages to derive the overall ship estimate and (2) <u>begin</u> with the ship's overall characteristics and estimate the probable development costs by deduction [Ref. 1:p. 3-8]. The method used depends largely upon the relevant historical data and the level of technical complexity or innovation [Ref. 2:p. 4-54].

The detailed estimation approach is commonly called the "bottom up" or Engineering approach. It involves breaking down the ship into separated and identifiable segments of work.

The breakdown is accomplished by the Expanded Ship Work Breakdown Structure (ESWBS), (which will be described later in detail). Once, these elements are refined, developmental costs are estimated using (when available) historical cost data and simply totaled for each level. An overall developmental cost estimate consists of a summation of the individual development costs of each task element [Ref. 1:p. 4-8].

The second of these generalized techniques is in concept, a reversal of the bottom up approach. Here, the composite project is viewed as a series of physical or performance characteristics. These attributes in turn are compared with relationships from earlier projects, forming Cost Estimating Relationships (CER's). In total, the results of these CER's are used to form the development cost estimate, producing a Parametric or "top down" cost modeling technique.

E. ESWBS WEIGHT GROUPS

The Expanded Ship Work Breakdown Structure (ESWBS) provides a common means of communicating the level of technical definition between the ship designer, shipyard and cost estimator. It integrates design with logistics, using standard classifications of the ship itself, the ship systems, and the combat system. The major elements of the ESWBS system of interest to ship costing are listed in Table 2.2 [Ref. 1].

Note that ESWBS Groups 800 and 900 although a part of the of the work breakdown structure, deal with engineering and design support. Therefore, these items are not required to physically describe the technical aspects of the ship.

Consequently, the summation of the One-digit ESWBS Groups 100 - 700 (normally referred to as the "functional technical groups"), is equal to the weight of the whole ship less load items.

ESWBS Group	Description
100	Hull Structure
200	Propulsion Plant
300	Electric Plant
400	Command & Surveillance
500	Auxiliary Systems
600	Outfit & Furnishings
700	Armament
800	Design & Engineering Services
900	Construction Services

Table 2.2
ESWBS One-digit Weight Groups

The ESWBS classification system allows the ship to be specified at any of three level; one-, two-, and three-digit. Each higher level indicates a higher degree of technical definition, as can be seen from the examples in table 2.3. The three-digit ESWBS level represent the highest level of definition.

All of the ship costing techniques discussed in this study will apply the ESWBS weight groups as the means to classify weights.

ESWBS Level Breakdown	'echnical Description
-	Whole Ship
1-digit Weight	Hull Structure - Group 100 Electric Plant - Group 300
2-digit Weight	Hull Decks - Group 130 Lighting Systems - Group 330
3-digit Weight	Second Deck - Group 132 Lighting Fixtures - Group 332

Table 2.3
Examples of Increasing ESWBS Level of Technical Definition

F. ESTIMATE QUALITY

Estimate quality is related to a variety of factors, the majority of which are programmatic in nature (i.e., acquisition strategy plans). NAVSEA uses a cost estimate classification system which assigns letters of the alphabet to indicate estimate quality.

In increasing level of design definition or, decreasing level of uncertainty, are Rough Order of Magnitude (ROM), Class F, D, C. Additional categories exist, but their nature is beyond the scope of this discussion. Table 2.4 shows the ESWBS level of technical definition appropriate for each category of estimate classification. [Ref. 1:p. 4-9]

Estimate Classification	ESWBS Technical Definition	NAVSEA Cost Phase
ROM	Less than Feasibility Study	Planning
F	Feasibility Study 1-digit Weights	Planning/ Programming
D	Preliminary Design 2-/3-digit Weights	Programming (maybe Budget)
C	End Preliminary Design 3-digit Weights	Budget

NAVSEA Ship Cost Estimate Classifications
Table 2.4

This study is concerned with ship cost estimating as the estimate progresses from the feasibility to the preliminary design phase, corresponding to the Class F estimate becoming a Class D. The technical level of definition for this progression starts with the one-digit ESWBS group. Therefore, the primary technical input to the estimator for this degree of quality will be an approximate weight for each of the functional technical groups (ESWBS groups 100-700). Of course, one-digit ESWBS weights can be calculated by a simple summation of the weights of higher level components as they become available.

III. FUNDAMENTALS AND METHODS ESTIMATING SURFACE SHIP COSTS

A. INTRODUCTION

This chapter will describe in greater detail, the method used by NAVSEA's cost estimation branch. It is a system designed to function within the Navy's existing cost collection/ accounting system, with significant amounts of technical and cost data, all integrated by a computer controlled cost modeling system. The procedures described are the rudiments, on an elementary level, of the NAVSEA "Unit Price Analysis" model itself.

Provided first are some of the basics required of those within NAVSEA, chartered with the task of estimating the weights assigned the various ESWBS groups. Briefly addressed are areas of variance in these weight estimates with a review of the accuracies achieved in past endeavors. This will provide greater insight upon the criticality of accurate estimates and display the impact of those conclusions upon the costing procedures. Having described these procedures, the discussion will then continue with the cost estimation model itself.

For illustrative purposes, this chapter concludes with an overview of the procedures followed by the Naval Center For Cost Analysis and the David Taylor Naval Ship Research Center. The procedures followed by these organizations approach the task of cost estimation from avenues different than the NAVSEA method.

B. FUNDAMENTALS OF SURFACE SHIP WEIGHT ESTIMATION

The usual penalty associated with poor surface ship component weight estimation is a compromise of metacentric height or righting moment. This condition leads to degraded service life or costly corrections to compensate reserve buoyancy. However, since this research keys upon the cost estimate itself, inaccuracies of the weight estimate will be viewed as a penalty to the cost estimator.

Weight estimates of surface ships deal in displacement. That is, the weight of the vessel will displace the weight of the volume of an equivalent amount of sea water (one ton of ship displacement is roughly equivalent to the weight of 35 cubic feet of ordinary sea water). As this is intended to be a "broad brush" of a complex procedure, only three categories of weight information are addressed.

1. Known weights

The mass properties information are "given" for previously defined systems or components. For example, the component structures of a gas turbine module would be a given, as component weights are well established.

2. Probable weights

Probable weights are assigned to those components or systems whose presence is known but, whose mass properties are not sufficiently known to allow for a precise weight (or center of gravity) computation. This category of weights represents the majority of the estimate and undergoes the greatest transformation [Ref. 3:p. 128]. An example of probable weights would be in the consideration of two feed pumps. Either pump might meet performance specifications but the pumps may differ dramatically in physical properties (such as weight).

3. Margins

NAVSEA weight estimators separate out the remaining component of weight assessment into two areas; (1) Acquisition Margins: that which is expected to reflect the ship's weight at the time of delivery, and (2) Service life allowance: the growth component designed into vessel providing for modernization or future expansion of the ship's capability. [Ref. 3]

Figure 3.1 graphically displays the relationships of these components. Note that the probable weight component is the greater of all values during the design phase but as the vessel's project life continues, better definition of this value is developed (it becomes a "known").

C. ASSEMBLING THE WEIGHT ESTIMATE

Like the cost estimates, the weights are broken down by the weight estimator into ESWBS grouping by functional area. In an iterative process the weight estimator follows the time line of Figure 3.1, attempting to build the "known weight" component as the design becomes better defined. In essence, confidence builds in the "probable weights" category. The weight estimator accomplishes this by one of two means; (1) parametric: where weights are assigned to coefficients of historic data or (2) "computational" [Ref. 3:p. 129]. Here, the estimator applies his professional judgement to the plans, sketches and diagrams of the vessel based upon like or similar systems.

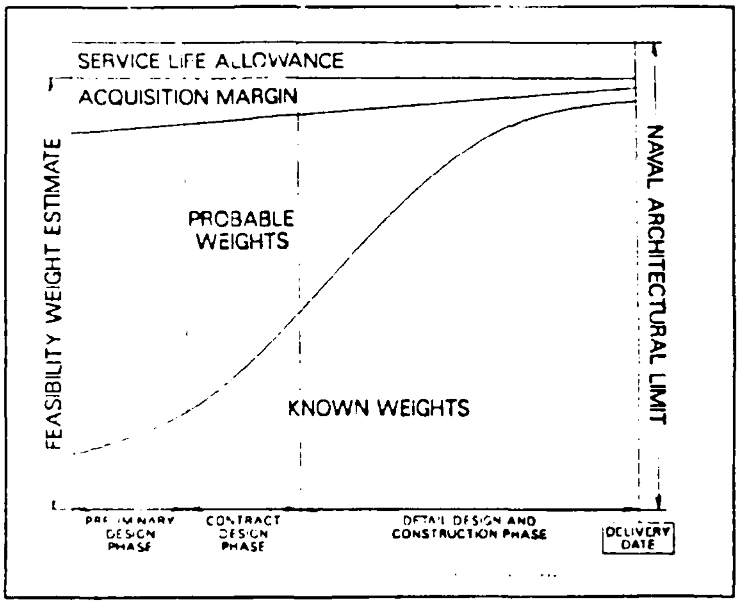

Figure 3.1
Design Time - Weight Profile

"Feasibility weight estimates" are the cornerstone upon which the cost estimator derives a cost of any accuracy up to a Rough Order of Magnitude. As cost estimators have differing levels of "quality" with their estimates, so as well do the weight estimators. Beyond feasibility, the evolution proceeds with "Preliminary design weight estimates", becoming most accurate with the "Contract Design estimates". The discussion will now shift its focus to how the weight estimates are selected.

Given a "lead ship" or any other parent vessel, the weight estimator is provided an ideal platform upon which to base his estimate. In a case of a new design, selected attributes of that design are likened to those of its' predecessors and the new construction vessel is built upon several "parent" ships. Having selected the attributes, the estimator can then establish a ratio from the parent (e.g., X1 amount of superstructure made of Y1 material versus X2 amount of superstructure made of the same material). Innovative designs may require the estimator to build the unknown components of the ratios (from the parent) around the new design knowns [Ref. 3:p. 130]. An example of this would be a new feed pump design where although its particulars are known, the attached shaftings and deck mounts would be initially likened to those from a parent vessel.

As technical definition becomes more certain, weight estimate quality is enhanced through better baseline/design information, becoming a hierarchial end product of a contract weight. In this final phase, the contract drawings with exacting nomenclature, positions, and materials are expected to be consistent with design specification requirements. [Ref. 3:p. 138]

Although the contract estimate is the best of the engineered weight answers, drawings and contracted language do not preclude the builder's flexibility with regard to performance specifications [Ref 3:p. 139]. Performance specifications are instrumental to some of the weight groups where the shipbuilder's solution options would be unduly restricted should more exacting design specifications be imposed. Additionally, one shipyard's procedures for accomplishing similar tasks may be different in the final weight analysis than another shipyard. According to one NAVSEA estimator's judgement, other areas for variance are simply "design changes which fell through the cracks" [Ref. 3].

D. AN INVESTIGATION OF THE ACCURACY OF THE WEIGHT ESTIMATE

For illustrative purposes, data from the aforementioned study (representative of the conclusions of the report) are presented in Table 3.1. The purpose of that research was to investigate (in hindsight), the accuracy of contract weight estimates versus the final weight report at the end of construction. Table 3.1 data are in a format of contract tonnage for the varying ESWBS group, elements of increase, elements of decrease, total change and net change. Summing contract weight and net change form the basis of the vessel's ending weights.

ESWBS Group		FFG 7		DD 963
Hull				
WEIGHT		1241T		2722T
INCREASE	71	5.7%	444	16.3%
DECREASE	64	5.1	61	2.2
CHANGE	135	10.8	505	18.5
NET	7	.6	383	14.1
Propulsion				
WEIGHT		257T		767T
INCREASE	64	24.9%	90	11.7%
DECREASE	34	13.2	104	13.5
CHANGE	98	38.1	194	25.2
NET	30	11.7	-14	-1.8
Electric Plant				
WEIGHT		187T		347T
INCREASE	21	11.2%	28	8.0%
DECREASE	12	6.4	91	26.2
CHANGE	33	17.7	119	34.2
NET	9	4.8	-63	-18.2
Command & Surveillance				
WEIGHT		94T		349T
INCREASE	27	28.7%	36	10.3%
DECREASE	6	6.4	31	8.9
CHANGE	33	35.1	67	19.2
NET	21	22.3	5	1.4
Auxiliary Systems				
WEIGHT		404T		643T
INCREASE	121	30.0%	130	20.2%
DECREASE	34	8.4	70	10.9
CHANGE	155	38.4	200	31.1
NET	87	21.5	60	9.3
Outfit & Furnishings				
WEIGHT		289T		532T
INCREASE	47	16.3%	45	8.4%
DECREASE	29	10.0	126	23.6
CHANGE	76	26.3	171	32.0
NET	18	6.2	-81	-15.2
Armament				
WEIGHT		94T		142T
INCREASE	3	3.2%	44	30.7%
DECREASE	4	4.3	34	23.6
CHANGE	7	7.5	78	54.3
NET	-1	-1.1	10	7.1

Table 3.1
Weights from Contract Design Weight Estimates

From the data, a cost estimator may conclude that although he is using weight estimates as "official", those weight figures are actually changing best-guesses. Additionally, the data reflect that the accuracies achieved by the weight estimators are prone to major swings in themselves.

The complete NAVSEA study reveals that the weight estimators understated the weights (net increase) in 59 of 84 groups, zero summed in one instance, and overstated the weight in 24 cases.

The difficulty in including "everything" in a weight estimate is understandable. The lesson learned for the users of the weight estimate (i.e., cost estimators) is that the preceding would portend the tendency to understate the weight estimate.

One conclusion of the weight study is that there exists "a need for greater accuracy in the weight estimating" [Ref. 3:p. 141]. The author of this paper therein makes recommendations upon his findings of fact.

E. FUNDAMENTALS OF SURFACE SHIP COST ESTIMATION

1. <u>General</u>

NAVSEA 017 is charged with the responsibility for preparing the Navy's <u>official</u> ship cost estimates for planning and programming purposes and for the annual Department of Defense shipbuilding budget [Ref. 1:p. 1-1]. These responsibilities encompass ship cost estimating and analysis at the initial design feasibility study phase through production award. NAVSEA 017 also emerges as advisor to the NAVSEA program management offices on the historic, current, and emerging trends in all elements of cost estimating and cost analysis.

The Cost Estimation office provides the input to the shipbuilding procurement account, Shipbuilding and Conversion, Navy Appropriation (SCN). These procurements, once authorized by Congress must be fully funded or else construction work ceases. This policy ensures that funds are available for all reasonable and expected costs through the ship construction and post-delivery period.

As every official NAVSEA ship cost estimate is to be treated as a potential budget candidate, certain requirements have been established to ensure the estimate is treated in its proper context [Ref. 1:p. 3-2]. These criteria are:

- A written OPNAV cost and feasibility request in hand
- Formal technical design inputs are available
- An approved acquisition strategy and shipbuilding schedule must be available
- A cognizant Program Manager must be involved

What is herein described as the NAVSEA cost method, unless otherwise specifically credited, uses the NAVSEA COST Estimator's Handbook as its basis, cited as Reference 1.

There are four principal divisions in the acquisition design process; feasibility studies, preliminary design, contract design and detail ships. The first three new ship design phases and their relationship to Acquisition Milestones are depicted in Figure 3.2. This figure also relates the estimate quality categories previously discussed.

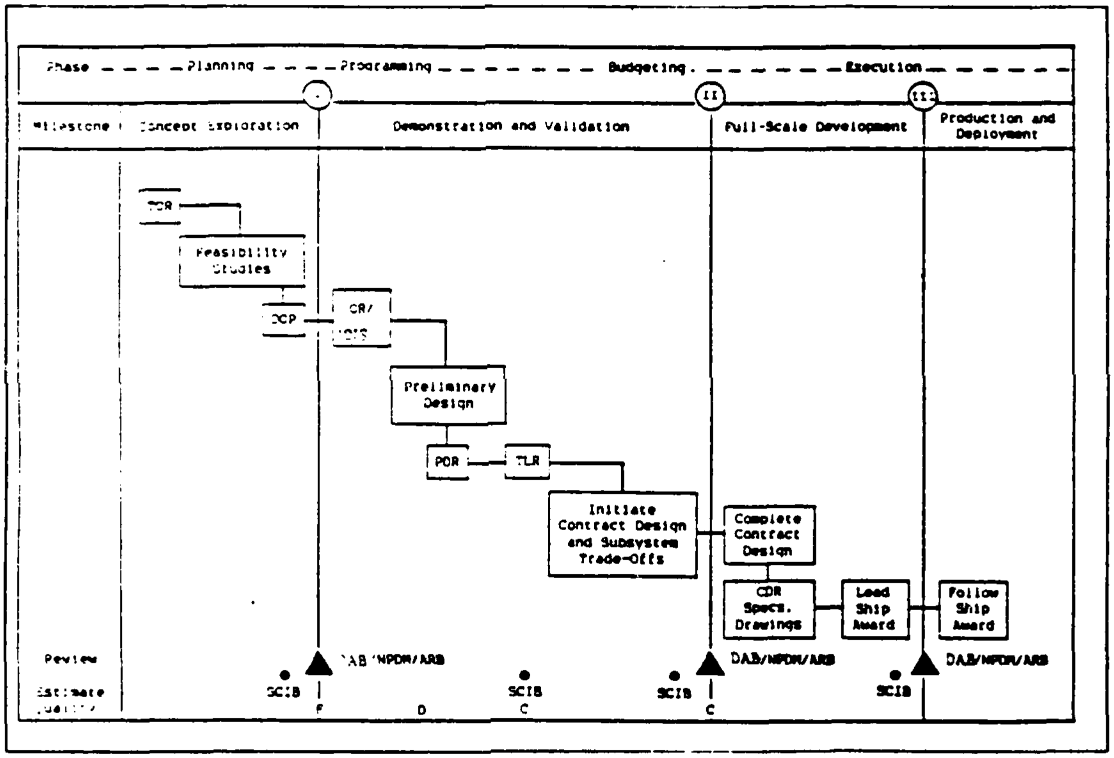

Figure 3.2
Acquisition Review Milestones, Technical Definition and Cost Estimate Quality

2. **<u>End Cost Estimate Categories</u>**

The results of the ESWBS weight versus cost form only one (albeit major) of the input variables to the "end cost" estimate. The relationship of EWSBS with Cost Categories is depicted in Figure 3.3. Note that a summation of the costs allocated from the ESWBS groupings provides the MCC 211, "Basic Construction" estimate. Routinely, the other major cost categories are presented in summary groupings of government furnished material (GFM), and "other". As previously stated, the major effort of this research investigated the derivation of MCC 211 estimates.

3. **<u>Other cost estimate categories</u>**

The categories listed above, which formulate the "end cost" estimate, will now be described in brief. The computed values for these variables are the result of a vast number of Cost Estimating Ratios, Unit Price Analysis modeling and estimator judgement.

<u>Construction plans (MCC 111)</u>: This represents costs of the builder's efforts to produce detailed construction plans from the NAVSEA contract drawings and specifications. Change orders are costed separately, under MCC 113.

<u>Basic construction (MCC 211)</u>: The basic construction category is the focus of this research and is the most demanding of the categories upon the estimator. Defined as the original contract award price for construction (or modification), this figure includes all direct costs, profit

plus overhead and is dollar indexed. MCC 211 predominates for new construction ships.

```
ESWBS GROUP                        MAJOR COST CATEGORIES

100    HULL STRUCTURE              CONSTRUCTION
                                   PLANS
200    PROPULSION                  MCC 111/113
                                        +             CONTRACT
300    ELECTRIC PLANT       --->BASIC CONSTRUCTION<-ESCALATION
                                   MCC 211             MCC 953

400    COMMAND AND                      +
       SURVEILLANCE                CHANGE ORDERS
                                   MCC 311/312

500    AUXILIARY SYSTEMS                +
                                   GFM ELECTRONICS
600    OUTFIT AND                  MCC 400
       FURNISHINGS                      +
                                   GFM ORDNANCE/AIR
700    ARMAMENT                    MCC 900
                                        +
800    INTEGRATION/                GFM H/M&E
       ENGINEERING                 MCC 525
                                        +
900    SHIP ASSEMBLY               GFM PROPULSION
       AND SUPPORT                 MCC 521
                                        +
                                   OTHER SUPPORT
                                   MCC 800
                                        +
                                   TEST AND INSTRUMENTATION
                                   MCC 541
                                        +
                                   STOCK SHORE SPARES
                                   MCC 533
                                        +
                                   PROGRAM MANAGER RESERVES
                                   MCC 951
                                   ____________________
                                   TOTAL DOLLARS
```

Figure 3.3
Categories of a Total End Cost Estimate

Contract escalation reserve (MCC 953): The purpose of this category is largely to compensate the shipbuilder for the projected inflation within industry over the relatively long lived production effort.

Change orders (MCC 311/312): For varying reasons, changes are required to a shipbuilding contract over the life of the project. Basic types of change orders are Headquarters Modification Requests (HMR), and Field Modification Requests (FMR). HMR´s (category 311) are initiated by NAVSEA and the FMR´s (category 312) are initiated by Navy Supervisor of Shipbuilding charged with the local responsibility for the contract.

Government furnished material (MCC´s 400/ 900/ 525/ 521): Government furnished material (GFM) is a generic term applied to the many elements of the contract which are the responsibility of the Government to provide the shipbuilder. The categories cited above are of the major items of GFM as it relates to the new construction shipbuilding effort. From Figure 3.1, MCC 900 includes "Air" should the platform require costs allocated to helicopter operations, and MCC 525 "H/M&E" is short for hull-mechanical-and-electrical. Beyond these two items, the listed nomenclature is self explanatory and should suffice for the purpose of this discussion.

Test and Instrumentation (MCC 541): Allocated normally to the lead ship only, MCC 541 are instrumentation and testing costs associated with placing the ship into service.

Stock Shore-based Spares (MCC 533): These "spares" are of major H/M& E equipment, stored remotely from the vessel, and are normally quite bulky (such as gas turbine engines and anchor chains).

Other support (MCC 800): Primarily a vehicle for "etc.." items to be included in the final cost figure, MCC 800 is a summary category. Included herein would be the various PMS implementation costs, commissioning ceremonies, contracted and in-house engineering services and the like.

Program manager reserve (MCC 951): This category of funds is designed to provide flexibility to the program manager for the "unforeseen" problems associated with shipbuilding contracts.

4. Cost Estimating Relationship

Cost estimating relationships used within NAVSEA 017 for feasibility and preliminary design phases, are calculated from selected manhour and material costs as a function of the weights from the seven major ESWBS groups. These factors are updated annually based on historical data as well as return costs on previously awarded shipbuilding contracts and the past year's bid data on new awards.

Labor manhours, MH (hrs) and material costs, MC ($M), cost factors are developed for each of the weight groups such that;

$$MH_i = KL_i \quad W_i \tag{3.1}$$

where Wi = selected ESWBS weight group (Light Ship Tons)

KL_i = selected manhour cost factor (hrs/Light Ship Tons)

$$MC_i = KM_i \; W_i \tag{3.2}$$

where KM_i = selected material cost factor ($M/Light Ship Tons)

Estimates of labor manhours and material costs for ESWBS groups 800 and 900 are typically estimated as a percentage of the sum of manhours and material dollars for groups 100 through 700, such that;

$$MH_8 = FL_8 \; (\; MH_1 \; + \; MH_2 \; +...+MH_7 \;)$$

$$MH_9 = FL_9 \; (\; MH_1 \; + \; MH_2 \; +...+MH_7 \;)$$

$$MC_8 = FM_8 \; (\; MC_1 \; + \; MC_2 \; +...+MC_7 \;)$$

$$MC_9 = FM_9 \; (\; MC_1 \; + \; MC_2 \; +...+MC_7 \;) \tag{3.3}$$

where FL_i = selected labor fraction (%)

FM_i = selected material cost fraction (%)

The design and builder's (D&B) margin is costed and included as part of basic construction on the assumption that the margin will be "used up" during the development of the design and ship construction. Margin costing is done by applying the D&B margin percentage to the total manhours and material dollars for groups 100 to 900 such that;

$$MH_{D\&B} = F_{D\&B} \; (\; MH_1 \; +...+ \; MH_9 \;)$$

$$MC_{D\&B} = F_{D\&B} \; (\; MC_1 \; +...+ \; MH_9 \;) \tag{3.4}$$

where $F_{D\&B}$ = D&B fraction (%)

For calculating labor costs, separate labor rates are employed for manufacturing and engineering operations. Manufacturing rates are applied to labor associated with ESWBS weight groups 100 to 700, 900 and the D&B margin. The engineering rate is applied to the labor required for ESWBS group 800 work. For any given labor rate, the labor cost, LC ($M), is given by the expression;

$$LC_i = MH_i \ \$/hr \qquad (3.5)$$

where $/hr = selected labor rate (dollars per hour)

Overhead costs, OV ($M) are calculated as a percentage of the labor costs associated with each of the ESWBS groups such that;

$$OV_i = F_{ovhd} \ LC_i \qquad (3.6)$$

where F_{ovhd} = labor overhead fraction (%)

The cost of construction for each ESWBS weight group plus margin, C ($M), is the addition of material cost and direct and overhead labor costs such that;

$$C_i = MC_i + LC_i + OV_i \qquad (3.7)$$

The cost for each ESWBS group can then be summed to arrive at the intermediate ship construction cost, C_{cc} ($M), where;

$$C_{cc} = (C_1 + C_2 + \ldots + C_9 + C_{D\&B}) \qquad (3.8)$$

A "cost of money" (COM) compensates the contractor for the cost of providing capital for their facility investments. Government standards specify the fraction of the facility costs that contractors can treat as capital invested in the marketplace. The rate of return allowed on these investment costs is in essence, an imputed interest.

The COM is calculated by multiplying the sum of the estimated direct labor costs by an appropriate factor. This is the product of the shipbuilder's net book value of assets and the imputed interest rate all divided by a labor cost allocation base The base is set equal to the direct labor dollars expended in the shipyard for a particular year. The equation is;

$$COM = F_{com} \, (LC_1 + \ldots LC_9 + LC_{D\&B}) \qquad (3.9)$$

where F_{com} = the COM factor (%)

$$= \frac{\text{(net book value) (imputed interest rate)}}{\text{(allocation base)}}$$

Profit is the final element of the basic construction cost estimate. Profit, C profit (\$M), is calculated as a percentage of the sum of all ESWBS groups plus margin costs. Expressed as:

$$C_{profit} = F_p \; C_{cc} \qquad (3.10)$$

where F_p = profit fraction (%)

and C_{cc} = the estimate derived from equation (3.8)

After the profit dollars are calculated, the construction costs, cost of money and profit are summed to arrive at a complete basic construction price, P_{bc} (\$M), where;

$$P_{bc} = (C_{cc} + C_{profit} + COM) \qquad (3.11)$$

All elements of the basic construction price are adjusted to a common dollar base year.

Shipbuilding contracts are generally costed to a given near-term base date. The contracts include an escalation clause to reimburse the builder for inflation occurring in the shipbuilding industry over the contract's life. The dollar amount estimated specifies a building period and assumed labor outlay profile.

5. **Shipbuilder learning curve**

Some of the price allocated to the lead ship of a class will be "non-recurring" costs, occurring primarily in the stock shore-based spares, test and instrumentation, and construction plans categories. In the shipbuilder's portion however, learning is assumed to take place. Corrective factors for these learning rates are applied to both manhour and material dollar estimates (Equations 3.1 and 3.2). These reductions are reflected in a reduced basic construction price, P_{bc} (Equation 3.11).

Values for the learning rates are estimated from historical cost data. Procedures for deriving learning curve values are provided in intermediate accounting and statistics texts. NAVSEA sights a typical labor learning rate, applicable to both direct labor and overhead, ranging from 90-94%.

6. **The Budget estimating (P-8) format**

The Unit Price Analysis cost estimating program gives a cost breakdown of lead and follow-on ship material, labor, overhead and total acquisition (end) costs. There are two classes of cost information provided as the output; one is a one digit ESWBS group summary, NAVSEA Form 4280/2 "Unit Price Analysis - Basic Construction", and the "P-8" estimating format.

For budget purposes, acquisition costs are documented using the P-8 format, providing the end cost estimates in a format listed in Table 3.2.

MCC	Category
100	Plan Costs
200	Basic construction costs
300	Change orders
400	Electronics (GFM)
500	H M & E (GFM)
800	Other costs
900	Ordnance (GFM)
951	Program manager growth
953	Escalation

Table 3.2
P-8 Output Summary

F. OTHER US NAVY AGENCIES' SHIP COST ESTIMATION METHODS

1. The Naval Center for Cost Analysis

Another agency which performs ship cost estimating for the US Navy is the Center for Cost Analysis (NCA). NCA is chartered with providing the Chief of Naval Operations an independent cost analysis of varying projects, one of which is surface ship cost estimation. The primary method used by the Center for estimating basic ship construction costs, is the "GIBBS & COX" model. The model is based upon shipyard generated cost data, extracted from their analysis of actual returned costs for six ships. Table 3.3 indicates the ship classes used in the database. All of the listed ships were built at Bath Iron Works (BIW) in Bath, Maine.

Ship Class	DD 931	DDG 2	CG 16	CG 26	FFG 4	FFG7
Number Built	14	23	9	9	6	8*
Year Comm.	55-59	60-64	62-64	64-67	66-67	77-80*
BIW Delivery Date	11/55	8/60	7/62	11/64	4/67	11/77
Full Disp.	3960	4500	7800	7900	3426	3605
Lgth	407	420	510	524	414	408

* as of 1980

Table 3.3
GIBBS & COX Ship Database

Although the GIBBS & COX has its roots from the current (and past) NAVSEA methods, this method focuses upon a two-digit breakdown of 22 differing cost groups rather than NAVSEA's three-digit ESWBS groups. Per the GIBBS & COX model, the 22 cost groups are extracted from the NAVSEA

ESWBS categories 100-700 according to the "behavior" of the costs within a subsystem grouping [Ref. 4:p. x]. Designed to address the cost estimate with a point of view independent of NAVSEA, the model makes a differing set of assumptions on the contract design.

Systematically, the GIBBS & COX builds the cost estimate from the cost groups with specific, correcting "algorithms" of labor and material costs [Ref. 4:p. viii]. The algorithms use a linear least squares regression technique as their basis of formulation. Other inputs required by the model are weight estimates, and other variables such as an estimate of the platform's shaft horsepower, or installed generating capacity. Once the input variables are identified, additional, specific algorithms are applied to these "cost drivers" [Ref. 4:p. x]. Otherwise, the variables are graphically fitted to developed linear traces, derived from the algorithms.

The sum of these GIBBS & COX cost drivers form the yard's associated cost of the vessel (in principle, resembling the NAVSEA MCC 211 estimate), excluding GFE and armament [Ref. 4]. Costs for these items are not normally included in the NCA estimate, but should they be called for, the Center in essence utilizes the NAVSEA derived figures.

2. David Taylor Naval Research and Development Center

An entirely different point of view of the surface ship cost estimate is taken of the David Taylor Research

Lab. Here, futuristic ship designs and concepts are explored by naval architects and engineers. The vessels under investigation by DTNSRC are of far less technical definition than the near construction ships costed by NAVSEA and NCA. Consequently, the price modeling used by David Taylor requires yet another, different focus than the two methods previously discussed. For price modeling of their exploratory designs DTNSRC has in the past used two methods, ASSET and RCA PRICE.

A. ASSET, an acronym for Advanced Surface Ship Evaluation Tool, addresses most of the technological domain of naval architectures that are relevant to the design of Navy warships [Ref. 5]. ASSET was developed by Boeing Computer Services Company for David Taylor and is intended for use in the exploratory and feasibility phases of the ship design process. According to DTNSRC cost estimators, the ASSET program has proven useful in assessing a variety of whole ship technology impacts in a consistent manner.

Technical information, ship data, algorithms and empirical formulae instrumental to the ASSET method were supplied by NAVSEA. At the present time, the DTNSRC center has developed estimates from the ASSET model of the hydrofoils, monohull surface combatants and SWATH (Small Waterplane Area Twin Hull) ships.

The basis for the following description of the ASSET method is the ASSET manual, cited as Reference 6.

ASSET is divided into three sections; initialization, synthesis and analysis. During initialization, the data entered to define the current ship is checked for completeness and obvious, "fatal" errors. Next, the data is synthesized until an integrated ship design is achieved, in that each element of data that defines the ship is consistent with every other element of ship data. Once the design has converged, various analyses, such as cost, are carried out. Figure 3.4 depicts the ASSET process in general.

```
Initialization              Initialization
------------------------------------------
Start
Hull Geometry
Hull Structure
Resistance
Propeller (Drive)             Synthesis
Machinery
Weight
Design Summary

Convergence---->   NO
            |
            Yes
     End
------------------------------------------
Performance                   Analysis
Hydrostatics
Seakeeping
Cost
Space
Manning
```

Figure 3.4
ASSET Computational Modules

B. David Taylor cost estimators have most recently implemented the RCA PRICE method for the advanced vehicle design estimates. RCA PRICE is from a family of automated, parametric, cost estimating models. PRICE, an acronym for Programmed Review of Information for Costing and Evaluation) was originally developed for internal RCA use in the early 1960's. Commercial operations began in 1975, with applications to hardware development and production, software design and implementation, microcircuits and associated maintenance support costs. Figure 3.5 provides a listing of the diversity offered by PRICE modeling systems

PRICE MODELS
- -Hardware
- -Software
- -Life Cycle Cost
- -Microcircuits

ENGINEERING
- -New Products
- -Updates
- -Enhancements
- -Custom Software

PRICE SYSTEMS

OPERATIONS
- -Customer Support
- -Symposia
- -Timesharing
- -Documentation
- -Training

MARKETING
- -Presentations
- -Sales Assistance

Figure 3.5
PRICE Parametric Modeling System

For ship acquisition cost estimating, the PRICE H model is the method of choice by DTNSRC. The model estimates costs associated with design, drafting, project management, documentation, engineering, special tooling and test equipment, material, labor and overhead [Ref. 7:p. 10]. The PRICE method is characteristic of methods used by NAVSEA and NCA in that one of its outputs is a cost per pound basis. Unlike the other methods however, this output does not contain a breakdown of material and labor costs. This figures are synthesized using the "PRICE LABOR" algorithm or other post-processing device.

At this point, the author notes his personal opinion that traditionalist cost estimators have less than full confidence in the PRICE method for the above reason and others which follow. Additional items precluding acceptance of PRICE are (1) the PRICE models are proprietary and consequently must be operated as a "black box"; (2) it was originally developed for avionic and aerospace applications; and (3) once the material and labor costs are post-processed, the output is not suited to the (current) PPBS budget estimate requirements nor a Program Manager's material list and labor cost tracking needs.

Cost estimates obtained using PRICE are generally intended for acquisition planning purposes, but can estimate costs at any level of detail from a whole ship view down to individual components.

What follows as a description of the PRICE H method, uses the PRICE handbook as its basis, cited as Reference 7.

The PRICE H model estimates costs for both development and production elements of the program under review. Table 3.4 provides a listing of the categories included under the development and production cost headings.

The basis for the development of the PRICE proprietary CER's is a multiple regression curve fitting of historical data. The result of this analysis is literally thousands of mathematical equations relating to the various input variables to cost.

	Cost Category	Description
Development	**Engineering**	- drafting, design, systems engineering, project mgt and data
	Manufacturing	- labor and material associated with prototype production - tooling and test equipment
Production	**Engineering**	- non-recurring production costs
	Manufacturing	- production costs - tooling and test equipment costs

Table 3.4
PRICE H Cost Output Categories

Input data consists of 67 variables used to describe the physical, qualitative, programmatic, economic, and engineering characteristics of the system under review. RCA states however, that the model was designed to estimate costs with a minimal amount of hardware information, as missing input variable values are internally (to the program) generated. This feature makes the model most useful to DTNSRC, estimating costs in the conceptual stage of development. Logically, RCA cautions that the proper user specification of all the input variables will reduce the statistical uncertainty of the model.

Parameters fundamental to the PRICE method are listed in Table 3.5. Weight (here, based upon NAVSEA ESWBS or DTNSRC estimates) and manufacturing complexity are the most powerful of the RCA cost drivers.

Description
Number of production units built
Learning curve
Integration difficulty
Production Schedules
Development Schedules
Weights
Amount of new design required
Operational environment
Manufacturing complexity
Technological improvement

Table 3.5
Fundamental Cost Drivers in the PRICE Model

Separate manufacturing complexities are computed for mechanical/structural and electronics items. Ship costing applications are almost exclusively based upon estimated mechanical / structural complexities (MCPLXS). The complexities, MCPLXS, are in terms of a cost/lb for manufacturing processes and a cost/drawing (or effort) for engineering work. Values for MCPLXS are wide-ranging, depending upon the technology required for its fabrication, the operating environment and the employment history of the manufacturer.

The PRICE model then "calibrates" the basic user inputs for cost, schedule and physical characteristics. The model performs iterations upon the MCPLXS values until a complexity is calculated, "matched", for the specified input element. The more highly calibrated, the more certainty is afforded the estimate output by the DTNSRC estimators.

IV. REGRESSION ANALYSIS OF COSTS vs WEIGHT ESTIMATES

A. INTRODUCTION

In a preceding (1970) study, K.C. YU developed a simple regression equation for "contractor's estimated production cost" versus displacement tons over a broad reaching sample of US Navy Combatants [Ref. 8]. Initially developed herein is a similar model, applied to a more recent sample, limited to US Navy surface escort ships. Following this, the chapter provides an analytical technique in which the NAVSEA weight assessments for a ship are used as the independent variables in successive multiple regressions versus the dependent variable of (the NAVSEA) estimated basic construction cost (mcc 211 for each hull). Non-weight dummy variables such as contract type and ship factors, are added to the equations, to assess their impact upon the model.

B. BASIC DESCRIPTION OF LINEAR REGRESSION

Fundamentals of linear regression are provided in virtually all intermediate level statistics textbooks. Regression equations are in the form of an expected value of a dependent variable (Y_c) expressed as a function of the sum of a constant value (a) and the products of independent variables (x_1, x_2...,etc.) and their associated slopes (b).

A basic multiple regression equation is therefore:

$$Yc = a + b_1 x_1 + b_2 x_2 + b_3 x_3 \ldots + b_i x_i$$

Once the equation is developed from historical observations, the model will provide predicted values of the dependent variable, based upon the input independent variables, within a relevant range of the data.

For each regression equation, various statistical measures for the robustness of the model exist. One such measure is known as the "standard" error which is an indication of the reliability and precision of the equation as a predictor. Based upon the properties of the normal curve, statistics demonstrate that 68% of the time, the predicted values lie within a range of plus or minus 1 standard error and that 95% of the time, the predicted values lie within a range of plus or minus 2 standard errors. Other measures will be introduced later in the discussion.

C. PROCEDURAL FRAMEWORK

1. The MINITAB Program

Unless otherwise stated, the graphic presentations of the data and the statistical calculations were performed using the MINITAB desktop computer program. A sample MINITAB printout is provided as Figure 4.1. The figure will be used to introduce the program output as well as the procedural basis.

2. The "t-ratio"

As depicted in Figure 4.1, immediately following the derived equation, MINITAB provides an analysis of the variables forming the regression.

The "t-ratio" is a measure of the significance of the explanatory variables' corresponding slope, higher values associated with greater contribution. More simply, this measure states how well the explanatory variable predicts the dependent variable. As a matter of routine, the analysis strives to attain t-ratio values exceeding 2.0.

```
The regression equation is
84$sumd = 40196 + 0.354 then$

Predictor        Coef        Stdev    t-ratio
Constant        40196         5882       6.83
then$         0.35356      0.02221      15.92

s = 36132        R-sq = 74.7%     R-sq(adj) = 74.4%

Analysis of Variance

SOURCE        DF          SS           MS         F
Regression     1 3.30796E+11 3.30796E+11    253.38
Error         86 1.12277E+11  1305548672
Total         87 4.43073E+11

Durbin-Watson statistic = 0.49
```

Figure 4.1
Sample MINITAB output

3. __The standard deviation of the regression and "R-sq"__

Continuing with Figure 4.1 is the "s" or standard deviation of the regression (also called the standard error). The analysis will focus on regression models which minimize this measure. The next listing is the "R-sq" which is the measure of the equation's ability to explain the variation in the dependent variable. This measure is a function of the amount of the explained variation of the dependent variable versus the total variability. Perfect explanation occurs at 100% and the analysis focus is to maximize this number.

4. The Analysis of Variance

In the "Analysis of Variance" section of Figure 4.1 MINITAB displays the mean squares of the regression and its error (residual). The F statistic is a direct function of these values and is a measure of the overall efficiency of the regression. The F statistic is impacted by the degrees of freedom but roughly speaking, the analysis sought higher values for the measure.

5. Durbin Watson and Auto-correlation

The data were drawn to provide the most broad reaching measure available to "escort" surface ships. Consequently, random sampling was in no way achieved, and the analysis is therefore vulnerable to the onset of autocorrelation (serial correlation). The Durbin Watson statistic was monitored to keep the analysis within a 95% level of significance.

D. THE DATA

As previously mentioned, the data were provided by NAVSEA 017 from various files within their organization. The ships were drawn from available files on all recent US Navy vessels of "escort" nature. The vessels cited consist of a bank of 48 FFG's, 31 DD's, 4 DDG's and 5 CG's. All of the costs used in the research are provided from data which are proprietary in nature, the property of NAVSEA 017. These data are not intended for any usage other than this thesis and the confirmation thereof. All pertinent data are provided in the Appendix, and due to the proprietary limitation cited above, intentionally masked from specific hull number association efforts.

Table 4.1 provides a legend for the data labels used herein.

1. <u>Constant year dollars and the price deflator</u>

As the data cover a substantial range of construction years, the need for constant dollars is apparent. Due to the lengthy period cited of US Navy ship construction, projects of several varied disciplines, a broad measure for constant year dollars was chosen (BLS "GNP price deflator"). This deflator was utilized at the concurrence of NAVSEA 017 estimators.

The costs associated with the vessels cover a contracted period of time in themselves and an additional corrective measure upon the timing (of the deflator) was required. The method chosen was recommended by the 017 estimators and consists of a mid-point selection between the contract award date and the delivery date (cited as "mid-date" in Table 4.1).

Data label	Representing
mid-date	calender basis for constant $correction
dfltr	B.L.S. "GNP" deflator
cost	**MCC 211 + Changes, 1984 constant (K)$´s**
hull	ESWBS weight group...hull
prop	ESWBS weight group...propulsion
elec	ESWBS weight group...electric plant
cmd&s	ESWBS weight group...cmd & surveillance
aux	ESWBS weight group...auxiliary sys
out&f	ESWBS weight group...outfit & furnish
arm	ESWBS weight group...armament
swbtot	total platform weight
logcst	**log transformation of cost**
logwt	log transformation of swbtot
cntrk	dummy variable for contract type
escdumy	**dummy variable for "homogeneous" escort**
residual	error
Ycost	predicted Y (Y_c)

Table 4.1
Data Legend Table

Corrected dates were rounded to the nearest calender quarter prior to the application of the GNP deflator. The mid-dates are presented in the Appendix, formatted "Quarter.Year".

All costs used in the research have been accordingly changed to reflect constant year (K)dollars for the year 1984.

2. **MCC 221**

The dependent variable of choice was that most closely related to the ESWBS weight estimates, "shipbuilder costs" or MCC 211. This is a significant portion of the end cost estimate.

The data provided the researcher consists of the contracted costs and the limitation of this variable (the variable is physically not the "cost estimate" derived from the ESWBS weights) is noted. Actual estimates are changed throughout the budgetary and contracting phases, and the NAVSEA method recognizes only the most recent dollar figure available. Consequently, NAVSEA data are continually updated to reflect to actual or returned costs to the contract. Original estimate data are therefore not available to the researcher and the figures cited were the most recent available (February, 1988).

Costs (in K-dollars) from MCC 211 were summed with MCC 311/312 (forming data label "cost"), for the following reasons. First, except for one notable exception (a lead ship), these values were not material. Secondly, no specifics which required the "changes" were provided the researcher. Therefore, the assumption that change orders were not a function of weight estimate corrections could not be made.

3. The population

A simple histogram of the dependent variables from the population is provided in Figure 4.2. With the histogram is a display of the same data in boxplot format.

Although the histogram clearly is skewed, it also reflects (an anticipated) potential for data outliers. Additionally, the first two ordered frequency counts are a significant portion of the population. The boxplot displays the cited potential for outliers again, but note that the potential for symmetry also exists.

If linear correlation between the dependent and explanatory variables exist, it would best be visually displayed by the MINITAB "plot" function. Should this basic scattergram of the X and Y variables align data points along a 45° line passing through the origin, perfect linear correlation would exist. Figure 4.3 is the scattergram of the dependent variable and the explanatory variable for total platform weight. Note that the data align themselves into clusters, with few exceptions. This will be addressed later in the discussion.

Although a linear relationship apparently exists, the visual linear "fit" becomes a subjective one, with multiple potential candidates. One such subjective candidate has been scribed on the scattergram.

Figure 4.4 displays an alternative scattergram of the dependent variable, transformed, versus the explanatory total weight. Additionally provided is the boxplot and histogram of this transformation. Note that the log transformation of Y is visually similar to the basic plot displayed earlier. Also, potential exists for symmetry as shown by the boxplot.

```
Histogram of cost   N = 88

Midpoint    Count
 50000       29   *****************************
100000       44   ********************************************
150000        4   ****
200000        3   ***             * = data point
250000        4   ****            # = # points
300000        1   *               I = quartile
350000        2   **              O = outlier
400000        0
450000        1   *


                ------
             --I  + I----      ***  O  OO    O O        O
                ------

           -+---------+---------+---------+-------+cost

          80000     160000    240000    320000    400000
```

Figure 4.2
Total Population Displays

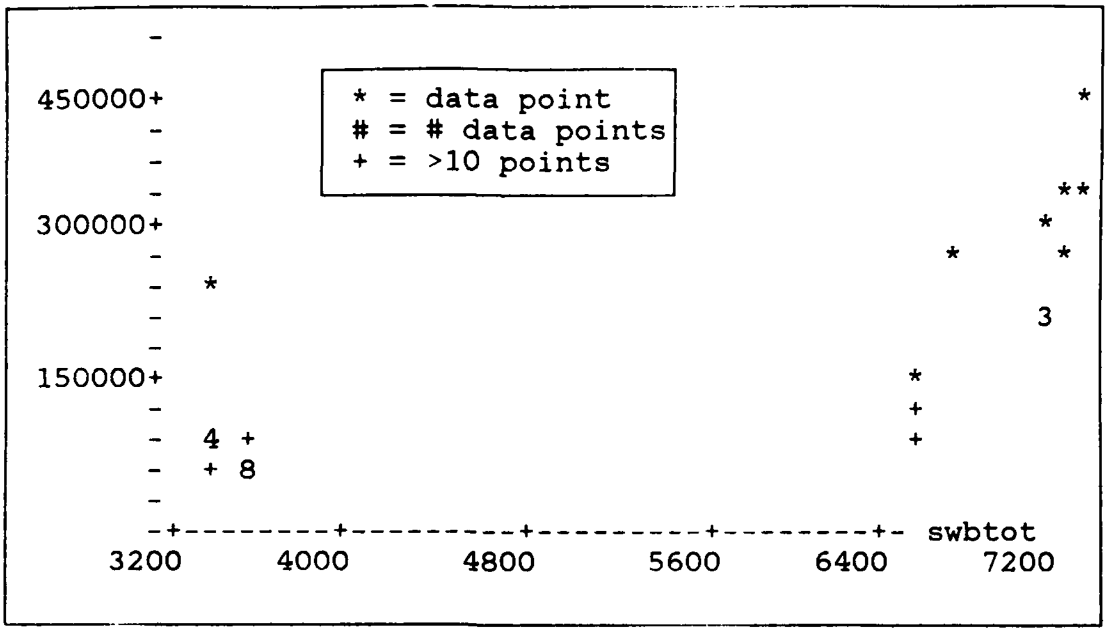

Figure 4.3
Scattergram of Dependent and Explanatory Variable

4. <u>The explanatory variables</u>

This thesis proposes that the explanatory variables (for ESWBS weights) can be formatted into linear regression equations which predict the related dependent variable of costs. Further introduction of the ESWBS weights used in the thesis data base is required.

The Appendix provides the listing of the component ESWBS weights cited by this research. The Appendix displays the weight groups by ship class "baseline" information. Sample size of the specific weights is small and the Appendix lists all of the ESWBS weights made available to the researcher.

```
       -                                             *
logcst -    *         * = data point
       -              # = # data points                   *
       -              + = >10 points                      2
   5.25+              I = quartile
       -              O = outlier
       -                                           *
       -                                           5
       -                                           +
   5.00+      4                                    8
       -    2 6                                    6
       -    2 4
       -    8 4
       -    7 4
   4.75+    6
       -
       -
       +--------+---------+---------+---------+-----swbtot
             3200      4000      4800      5600      6400
```

```
Histogram of logcst   N = 88

Midpoint   Count
     4.7       2  **
     4.8      23  ***********************
     4.9      15  ***************
     5.0      28  ****************************
     5.1       9  *********
     5.2       0
     5.3       3  ***
     5.4       4  ****
     5.5       3  ***
     5.6       1  *
```

```
                   -----------
             ------I     +    I-------------*  * **  **  O
                   -----------

        ------+---------+---------+---------+-----logcst
            4.80      5.00      5.20      5.40      5.60
```

Figure 4.4
Transformations of Dependent Variable

Inherent to the use of the baseline weights is the assumption that these weights can be applied to the specific hulls (within the baseline) without great compromise of the regression accuracy. Consequently, the data displayed in the population associates baseline weights with specific hulls in order to proceed with the regression.

Due to the above listed data base limitation, "clumping" of the data cited herein is artificially high. Although NAVSEA estimators assess this artificiality as minimal, impact upon the findings of this research is unknown.

Figure 4.5 presents the explanatory variable for total ESWBS weights in both histogram and boxplot format. Note that the data again clumps together and the potential for symmetry still exists. Additionally note that outliers exist, similar to preceding displays. The tendency of data clumping and outliers generate a need for further data base manipulation.

```
Histogram of swbtot   N = 88

Midpoint Count
  3000    48************************************************
  3500     0
  4000     0
  4500     0
  5000     0
  5500     0
  6000    31  *******************************
  6500     0
  7000     9  *********
                                 * = data point
                                 I = quartile
                                 + = >10 points

          -------------------------------------
          I +                   + I    ----------------
          -------------------------------------

    -----+---------+---------+---------+-------+swbtot
        3200      4000      4800      5600     6400
```

Figure 4.5
Presentation of the Explanatory Variable Total Weight

E. CORRECTION AND SEGREGATION OF THE DATA BASE

The data have been shown to present themselves in an apparent linear form, but possessing characteristics of both data clumping and outlier data points. These two sources of influence on the data base are not altogether unexpected. This is intuitive, given that the population is comprised of 5 CG's, 4 DDG's with the remainder (79 vessels) split among the larger groups of FFG's and DD's. Additionally, the data base includes the lead ships of each class. For these ships, builder costs have not been exposed to the cost saving benefit of the learning curve. To minimize the effects of these, this section presents alternatives for correcting the data base prior to the conduct of further analysis.

1. **Split the base into 2 sub-populations for DD´s & FFG´s**

The intention of the thesis is to investigate the behavior of "escort" costs as a function of the ESWBS weight estimates. The proposal of splitting the population would limit any conclusions derived and accordingly, this alternative is not considered adequate to the thesis intent.

2. **Discard the obvious outliers**

In order to prevent the undue influence of the cost outliers, one alternative would be to remove a portion or all of the outliers. Although this procedure is not as limiting upon the population as the preceding alternative, the process would introduce subjectivity in the researcher´s behalf.

Although researcher judgement would be exercised as to which outliers were selected for discard, this alternative would better satisfy the premise of "escort" cost behavior.

3. **Introduce a dummy variable to compensate the model**

Pragmatically, the comparison of the shipbuilding effort required upon an FFG-7 in 1977 is not altogether similar to the present day construction of an AEGIS cruiser.

Consequently, a dummy variable, without researcher bias, was sought in order to compensate the regression model.

A weighted average technique (of summed builder costs of construction plus change orders, "cost") was utilized in which the costing fraction of each escort class was captured in comparison to the total population. In this manner, an "homogeneous" escort would be given a comparative factor value of 1, and the other ship classes assigned corresponding relative weights. The factors produced by this technique are assigned as follows:

FFG...	0.6936
DD....	1.0159
DDG...	2.0161
CG....	3.0299

4. Selection of the alternative

Within the stated bounds of the thesis objective, the widest possible measure of escort cost modeling is desired. Additionally, introduction of "bias" in the rejection of outlier data points is to be minimized. For these reasons, the research proceeds with the analysis in two parts. First, data outliers corresponding to the 5 AEGIS cruisers and lead DDG are removed. These data points were the most conspicuously maligned and impart minimal restriction to the population (n=82). Secondly, an analysis will be conducted upon the entire population with the introduction of the "homogeneous escort" dummy variable outlined above. The separate avenues of analysis should synergize the resultant outcomes, provided conclusions may be derived.

F. ANALYSIS OF THE POPULATION, OUTLIERS REMOVED

A refreshed histogram and boxplot of the 82 data points is provided in Figure 4.6. With the reference scale changed, skewing remains on the histogram, although not as drastically as before. The potential for symmetry still exists on the boxplot display and is likewise marginally enhanced.

```
Histogram of cost   N = 82

Midpoint   Count
   60000      23  ***********************
   80000      17  *****************
  100000      28  ****************************
  120000       8  ********
  140000       1  *
  160000       0
  180000       0
  200000       2  **
  220000       1  *
  240000       1  *
  260000       1  *            * = data point
                               I = quartile
                               + = >10 points
                               O = outlier

             -----------
         ----I     +    I--------              ***      O
             -----------

    ----+---------+---------+---------+---------+----cost
      80000    120000    160000    200000    240000
```

Figure 4.6
Display of Revised Population

The histogram and boxplot display of the log transformed dependent variable is presented in Figure 4.7. These displays are the most normal presentations of the data thus far, both plots conclusively enhanced toward data normality. To assess linear fit, scattergrams and possible transformations are displayed in Figure 4.8. Note that no <u>conclusively</u> discernible difference exists in the assessment of linear fit for these modifications, including the log-log power transformation.

Accordingly, with the assumptions of linear fit and normality of the population met, the analysis proceeds with a log transformation of the dependent variable in addition to the unmodified Y.

```
                                          * = data point
Histogram of logcst   N = 82              I = quartile
                                          + = >10 points
Midpoint   Count
     4.7       2  **
     4.8      23  ***********************
     4.9      15  ***************
     5.0      28  ****************************
     5.1       9  *********
     5.2       0
     5.3       3  ***
     5.4       2  **

                       -------------
              -------I        +     I------------------* **
                       -------------

    +---------+---------+---------+---------+----logcst
   4.65      4.80      4.95      5.10      5.25     5.40
```

Figure 4.7
Log Display of the Dependent Variable

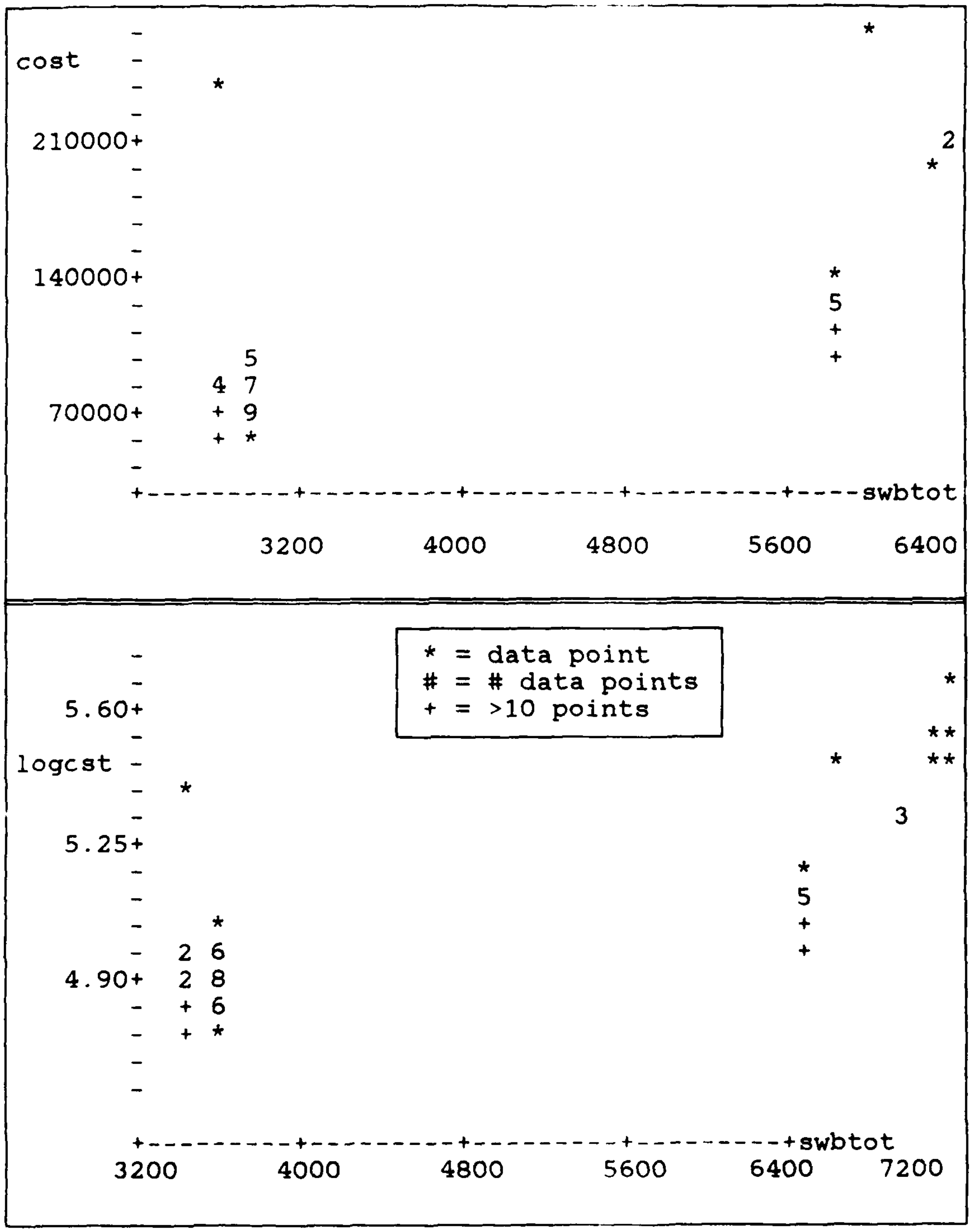

Figure 4.8
Scattergrams of Dependent and Explanatory Variables

```
       -                                              *
logcst -     *
       -                                                *
       -                                                2
   5.25+
       -
       -                                             *
       -                                             5
       -                                             +
   5.00+         4                                   8
       -     * * 6                                   6
       -     2   4
       -     3 5 4
       -     2 5 4
   4.75+     * 5
       -
       -

       +---------+---------+---------+---------+-----logwt
     3.440     3.520     3.600     3.680     3.760     3.84
```

Figure 4.8 (continued)
Scattergrams of Dependent and Explanatory Variables

1. Simple linear regression

The results of the MINITAB simple linear regression and their residual plots are provided in Figures 4.9(a) and 4.9(b).

Although the significance of the slopes and the regression efficiency is meaningful, the ability of X to predict Y and the standard error of these models is intolerable. Additionally, the residual plots indicate that the assumption of constant variance may be violated, with the potential onset of heteroscedacity in the pattern.

Although variance may be a function of data base limitations, the random arrangement of the residual pattern should be closely monitored. A better model to predict costs should exist. Note that the simple regression model functions significantly better with a transformed dependent variable. Testing the hypothesis that a power transformation may enhance the model, Figure 4.9(c) displays this iteration.

The log-log power transformation model (although substantially better than the unmodified regression), makes for a less powerful regression and predictor for the dependent variable than the simple logarithmic transformation. One possible conclusion from the above is that the linear behavior of the simple logarithmic model is superior to the log-log power transformation of the variables. It was previously displayed in Figure 4.8 that linear fit becomes subjective within limitations of the given data. For this reason (as well as brevity and simplicity), no further power transformations of the data will be displayed during iterations of multiple regression.

As the data provided the researcher made no allocation of the MCC 211 to the actual ESWBS component weight categories for this population, no further simple regression combinations are possible.

```
The regression equation is
cost = 30157 + 15.7 swbtot

Predictor        Coef       Stdev    t-ratio
Constant        30157       10245       2.94
swbtot         15.697       2.322       6.76

s = 31756       R-sq = 36.4%     R-sq(adj) = 35.6%

Analysis of Variance

SOURCE       DF          SS          MS         F
Regression    1 46088687616 46088687616     45.70
Error        80 80673718272  1008421504
Total        81 1.26762E+11

Durbin-Watson statistic = 1.11
```

```
         -
         -    *
     5.0+
         -                                                     *
residual-                    * = data point
         -                   # = # points
         -                   + = >10 points
     2.5+                                                        2
         -                                                       *
         -
         -
         -       *
         -    3* 9                                            *
     0.0+ -- 35 8 -------------------------------------------- 8 ----
         -    3+ 4                                             +
         -                                                     +
         -
         -
         -
         +---------+---------+---------+---------+----Ycost
       72000     84000     96000    108000    120000
```

Figure 4.9(a)
Simple Regression of cost

```
The regression equation is
logcst = 4.67 +0.000068 swbtot

Predictor        Coef        Stdev     t-ratio
Constant      4.67134      0.03311      141.07
swbtot     0.00006765   0.00000751        9.01

s = 0.1026       R-sq = 50.4%      R-sq(adj) = 49.8%

Analysis of Variance

SOURCE       DF          SS          MS          F
Regression    1     0.85596     0.85596      81.25
Error        80     0.84282     0.01054
Total        81     1.69878

Durbin-Watson statistic = 1.00
```

```
         -
         -
    5.0+    *
         -
residual-
         -                                                         *
         -
    2.5+
         -                                                            3
         -     *
         -  * *5                                                 *
         -  2*4*                                                 3
    0.0+ - *332 ---------------------------------------------    5 -----
         -  454                                                  +
         -  *6*                                                  7
         -   *
         -
         +---------+---------+---------+---------+------Ycost
       4.850     4.900     4.950     5.000     5.050     5.1
```

Figure 4.9(b)
Simple Regression of logcst

The regression equation is
logcst = 2.61 + 0.651 logwt

Predictor	Coef	Stdev	t-ratio
Constant	2.6142	0.2665	9.81
logwt	0.65126	0.07418	8.78

s = 0.1040   R-sq = 49.1%   R-sq(adj) = 48.4%

Analysis of Variance

SOURCE	DF	SS	MS	F
Regression	1	0.83359	0.83359	77.08
Error	80	0.86519	0.01081	
Total	81	1.69878		

Durbin-Watson statistic = 0.99

```
       -
       -
    5.0+    *
       -
residual
       -                                               *
       -
    2.5+
       -                                                3
       -
       -    *   *5                                    *
       -    2*  42                                    3
    0.0+ -- 23 - 22 ---------------------------------- 5 -
       -    36  4                                     +
       -    *5  *                                     7
       -     *
       -
       +----------+---------+---------+---------+--Ycost
       4.850     4.900     4.950     5.000     5.050
```

Figure 4.9(c)
Simple Regression with Log-Log Power Transformation

2. Multiple linear regression

From the preceding discussion, the two data sets of choice for further analysis are the log transformation of the dependent variable and the unchanged values for Y. This section of the research presents tandem comparison of models developed with these data sets. The effects of variable order were monitored in all multiple regression models herein and determined of no impact to the findings.

As all of the explanatory variables cited in this section deal with component ESWBS weights, a high degree of correlation is anticipated among the variables. Such is the case displayed by Figure 4.10, a correlation matrix.

	swbtot	hull	prop	elec	cmd&s	aux	out&f
hull	0.998						
prop	0.974	0.986					
elec	0.964	0.944	0.879				
cmd&s	0.998	0.993	0.967	0.968			
aux	0.963	0.943	0.878	0.993	0.966		
out&f	0.974	0.958	0.913	0.987	0.981	0.974	
arm	0.793	0.750	0.638	0.916	0.807	0.920	0.868

Figure 4.10
Data Correlation Matrix

With data so highly correlated, the onset of multicollinearity cannot be discounted. Accordingly, as the regression model is developed, explanatory variables of least contribution are stepwise dropped from the equation. This method will minimize multicollinearity effects within the developing model. In the next section, this procedure will be coupled with the "basket method" provided by the homogenous escort variable to further reduce the effect.

In the first iteration with all explanatory variables considered by the regression, "swbtot" (total weight) and "hull" drop from both equations. The printouts are provided in Figures 4.11(a) and 4.11(b).

There is substantial improvement in both equations from the simple linear case, with the log transformation (again) slightly better than its non-transformed counterpart. Residual plots reflect the desirable random pattern about the mean and none of the effects of heteroscedacity are present. Additionally note that the standard error has been reduced from prior attempts (the equations without transformation provide a lessening from 31756 to 20414 in "cost").

MINITAB's first iteration has automatically dropped total weight and hull weight from the prediction of the dependent variable. The high correlation of the total weight to the component parts (and the subsequent removal of the variable) is obvious, but the removal of hull weight warrants judgmental comment.

```
The regression equation is
cost = 729845 - 2512 prop - 162 elec + 6858 cmd&s - 1114
aux  - 505 out&f - 372 arm

Predictor        Coef        Stdev    t-ratio
Constant       729845       105338       6.93
prop          -2512.1        342.1      -7.34
elec           -161.7        651.6      -0.25
cmd&s          6857.8        857.9       7.99
aux           -1114.3        262.2      -4.25
out&f          -505.2        289.6      -1.74
arm            -371.8        316.1      -1.18

s = 20414        R-sq = 75.3%      R-sq(adj) = 73.4%

Analysis of Variance
SOURCE         DF           SS          MS          F
Regression      6  95508086784 15918014464      38.20
Error          75  31254315008   416724192
Total          81  1.26762E+11

SOURCE         DF       SEQ SS    SOURCE         DF      SEQ SS
hull            1  38414573568    elec            1 20676653056
cmd&s           1  24766623744    aux             1  9632431104
out&f           1   1441482368    arm             1   576326656
Durbin-Watson statistic = 1.04
```

```
     6.0+
        -                                          *
residual-                                                          *
        -    * = data point
        -    # = # points
     3.0+    + = >10 points                                          *
        -
        -
        -      *                  *                         3
        -      7       72 2       2
     0.0+ --   + --   3+ -------  3 -------------------------
        -      9   3  2           3
        -          3  *
        -
        -                                   4
    -3.0+
        -

        +---------+---------+---------+---------+--------+----Ycost
      60000     90000     120000    150000    180000
```

Figure 4.11(a)
Multiple Regression of all Explanatories

The regression equation is

logcst = 6.75 - 0.00773 prop + 0.00464 elec + 0.0214 cmd&s - 0.00408 aux - 0.00322 out&f - 0.00201 arm

Predictor	Coef	Stdev	t-ratio
Constant	6.7535	0.3684	18.33
prop	-0.007729	0.001196	-6.46
elec	0.004645	0.002279	2.04
cmd&s	0.021448	0.003000	7.15
aux	-0.0040759	0.0009168	-4.45
out&f	-0.003221	0.001013	-3.18
arm	-0.002006	0.001105	-1.81

s = 0.07139 R-sq = 77.5% R-sq(adj) = 75.7%

Analysis of Variance

SOURCE	DF	SS	MS	F
Regression	6	1.31657	0.21943	43.06
Error	75	0.38220	0.00510	
Total	81	1.69878		

SOURCE	DF	SEQ SS
prop	1	0.75438
elec	1	0.22321
cmd&s	1	0.14800
aux	1	0.11666
out&f	1	0.05755
arm	1	0.01677

Durbin-Watson statistic = 1.15

```
        -
     5.0+                             *
        -
residual-
        -
        -
     2.5+
        -
        -     *   *
        -         4 *     *  3           *
        -     3   2 2     3  5  2        2
     0.0+ --- 4 --*------- 3 -7---------- 3 ------------
        -     6   2 2     *              3            *
        -     *   3 2     *
        -     *     *     *
        -           *                           2
    -2.5+                                       2

        +---------+---------+--------+--------+------Ycost
        4.80      4.90      5.00     5.10     5.2
```

Figure 4.11(b)
Multiple Regression with Transformation

As previously stated, data were not available as to the component allocation of ESWBS weight group and group cost, merely the "total" allocation. A review of baseline weights provided in the Appendix indicates however, that a major portion of ships' weight is hull structure. Therefore, the researchers' conclusion on the removal of "hull" from the equations is that the cost of 1 ton of hull structure is less than the cost of other component weights.

Although the above results are encouraging, a large number of variables remain in the equations. Based upon their contribution (slope), the candidates for removal are "elec" (electrical plant) and "arm" (armament) in the case of the log transformation. An argument for removal of "elec" from the transformed case rather than "arm" could be made, but the next iteration mutes this point.

Of mention in Figure 4.12(a) is the marginal enhancement of the R-sq(adj), standard error and F statistics. Durbin-Watson remains within tolerance. The residual plot displays vitality of the residual, but the model carries one variable with a t-ratio out of tolerance. This variable is "arm", and its lack of contribution is not entirely unexpected from the prior iteration.

Figure 4.12(b) reflects similar results for the log transformation. Although R-sq(adj) shows a marginal decay, compensation occurs to the error and F statistics. Lastly, the removal of explanatory variable "elec" becomes apparent.

```
The regression equation is
cost = 728066 - 2494 prop + 6823 cmd&s - 1144 aux - 557
out&f   - 367 arm
```

Predictor	Coef	Stdev	t-ratio
Constant	728066	104443	6.97
prop	-2494.2	332.3	-7.51
cmd&s	6823.4	841.4	8.11
aux	-1143.6	232.7	-4.91
out&f	-557.4	198.0	-2.82
arm	-366.6	313.5	-1.17

s = 20287   R-sq = 75.3%   R-sq(adj) = 73.7%

Analysis of Variance

SOURCE	DF	SS	MS	F
Regression	5	95482421248	19096483840	46.40
Error	76	31279984640	411578752	
Total	81	1.26762E+11		

SOURCE	DF	SEQ SS
prop	1	38414573568
cmd&s	1	38685679616
aux	1	14367767552
out&f	1	3451548672
arm	1	562848000

Durbin-Watson statistic = 1.05

```
      6.0+
         -                                      *
  residual-
         -
         -
      3.0+                                     * = data point
         -                                     # = # points
         -                                     + = >10 points
         -        2      2                                     *
         -     6      43 2          2
      0.0+ ----+ --3  75 ------- 5 --------------------------
         -     8   3   2         3                              *
         -         3   *
         -                                                     2
         -                                      4
     -3.0+
         -
         +---------+---------+---------+---------+----Ycost
       60000     90000    120000    150000    180000
```

Figure 4.12(a)
Second Iteration

```
The regression equation is
logcst = 6.86 - 0.00629 prop + 0.00492 elec + 0.0186 cmd&s
-  0.00474 aux - 0.00339 arm

Predictor        Coef        Stdev     t-ratio
Constant       6.8628       0.3688       18.61
prop        -0.0062922    0.0009099      -6.92
elec          0.004917     0.002308       2.13
cmd&s         0.018604     0.002596       7.17
aux         -0.0047426    0.0008525      -5.56
out&f        -0.003389     0.001024      -3.31

s = 0.07246      R-sq = 76.5%     R-sq(adj) = 75.0%

Analysis of Variance
SOURCE         DF          SS          MS         F
Regression      5     1.29980     0.25996     49.52
Error          76     0.39898     0.00525
Total          81     1.69878
SOURCE         DF      SEQ SS
prop            1     0.75438
elec            1     0.22321
cmd&s           1     0.14800
aux             1     0.11666
out&f           1     0.05755
Durbin-Watson statistic = 1.14
```

```
       5.0+                            *
          -
  residual-
          -
          -                                                *
       2.5+
          -
          -   *   *                                          3
          -       4    2    3           *
          -   4   2   *4     2 2        2
       0.0+ - 3 - 2 -- 2* --- + ------- 6 ---------------------
          -   6   3    *                                       *
          -   *   *   3*
          -   *       *                       2
          -           2                       2
      -2.5+
          -
          +---------+---------+---------+---------+----Ycost
        4.80      4.90      5.00      5.10      5.20   5.3
```

Figure 4.12(b)
Second Iteration with Transformation

The third iteration will remove the explanatories "elec" and "arm" from both equations. Although the author has no defendable position to explain removal of the explanatory associated with electrical plant, its´ lack of contribution is apparent. From other data provided the researcher (not included for proprietary reasons), the lack of armament weight slope significance will be explained.

That portion of the cost of installing "armament" upon a naval combatant, associated by weight to the shipbuilders´ basic construction cost is not the sum total of the vessel´s armament. Indeed, a far more significant portion of the procurement end cost is allocated to the GFE used to arm the ship. As this thesis investigates the shipbuilder´s portion and not GFE, the contribution of the "armament" slope is consequently minor.

A third iteration follows as Figures 4.13(a) and 4.13(b). All slopes of the explanatory variables are now significant in the third iteration of Y, without the transformation. Here, R-sq(adj) is virtually unchanged, with little compromise to the standard error. The residual plot pattern remains robust for the error component.

In the equation with transformation, again similar results are achieved with four variables, with one exception. Note that the ability of X to predict Y is virtually equivalent in the equation <u>without</u> transformation.

```
The regression equation is
cost = 748680 - 2236 prop + 6312 cmd&s - 1257 aux - 572
 out&f

Predictor        Coef         Stdev      t-ratio
Constant       748680        103191         7.26
prop          -2235.9         248.9        -8.98
cmd&s          6311.9         720.5         8.76
aux           -1257.0         212.1        -5.93
out&f          -572.1         198.0        -2.89

s = 20336        R-sq = 74.9%     R-sq(adj) = 73.6%

Analysis of Variance

SOURCE        DF           SS          MS           F
Regression     4  94919573504 23729893376       57.38
Error         77  31842832384   413543264
Total         81  1.26762E+11

SOURCE        DF       SEQ SS   SOURCE          DF       SEQ SS
prop           1  38414573568   cmd&s            1  38685679616
aux            1  14367767552   out&f            1   3451548672

Durbin-Watson statistic = 1.07
```

```
      6.0+
         -                                           *
 residual-     * = data point
         -     # = # points
         -     + = >10 points                                      *
      3.0+
         -
         -
         -      2                         *                      *
         -      6     3 5 2               2                        2
      0.0+ ---- + --- 7 + ------------    6 ------------------------
         -      8     2                                          2
         -            5
         -            *                           2
         -                                        2
     -3.0+
         -
         +--------+---------+---------+---------+------Ycos
       60000    90000    120000    150000    180000
```

Figure 4.13(a)
Third Iteration

```
The regression equation is
logcst = 6.93 - 0.00673 prop + 0.0194 cmd&s - 0.00390 aux
 -  0.00181 out&f

Predictor        Coef        Stdev     t-ratio
Constant       6.9258       0.3760       18.42
prop       -0.0067261    0.0009069       -7.42
cmd&s        0.019431     0.002626        7.40
aux        -0.0039013    0.0007727       -5.05
out&f      -0.0018091    0.0007216       -2.51

s = 0.07410      R-sq = 75.1%     R-sq(adj) = 73.8%

Analysis of Variance

SOURCE        DF          SS          MS          F
Regression     4     1.27596     0.31899      58.09
Error         77     0.42281     0.00549
Total         81     1.69878

SOURCE        DF      SEQ SS
prop           1     0.75438
cmd&s          1     0.34870
aux            1     0.13838
out&f          1     0.03451

Durbin-Watson statistic = 0.98
```

```
     5.0+                          *
        -
 residual-
        -
        -
     2.5+
        -  *
        -  *     *
        -  4     3       2       *
        -  2     3*      3 2     3
     0.0+ -7-----2-------+------- 5-----------------
        -  6     2
        -  6      3
        -  2      2                   2
        -         *                   2
    -2.5+
        -
        +-------+---------+---------+---------+------Ycost
              4.90      5.00      5.10      5.20     5.3
```

Figure 4.13(b)
Third Iteration with Transformation

Although significance has been achieved in the slopes of both equations, a final iteration was performed in an attempt to further reduce the number of variables without undue compromise to the regression model. By a wide margin in both equations, the next candidate variable for removal is the explanatory associated with the outfitting and furnishing of the vessel, "out&f".

The MINITAB outputs for the fourth iteration are provided in Figures 4.14(a) and 4.14(b).

Although both models display some deterioration in their ability to explain Y, the compromise to corresponding standard error is slight. Similar to the third iteration, the Y element sans transformation, produces a marginal reduction of r-sq(adj).

3. Conclusions from the population

What was initiated as multiple regression with 8 explanatories has been enhanced to perform better regression with 3 or 4 explanatory ESWBS weights. The log transformation of the dependent variable produces better regression results than the uncorrected Y. Additionally, the removal of explanatory variables was accomplished with marginal degradation in the ability X to predict Y. In all cases, multiple regression has been displayed superior to the simple linear method.

The remaining variables which explain Y's variation correspond to propulsion, command & surveillance, and auxiliary systems. These variables remain in both equations with and without log transformation of the Y component.

A summarizing statement upon the equation explaining shipbuilder's costs with the ESWBS weight variables for propulsion, command & surveillance and auxiliary systems (without transformation) follows:

> The data reflect that ESWBS weight variables for propulsion, command & surveillance and auxiliary systems will predict shipbuilders' cost of the escort vessel with an R-sq(adj) value of 71.1%. Further, within a confidence interval of 95%, actual costs greater than 34886 (or 1.64 times the standard error) of the model's predicted costs should be reviewed.

G. ANALYSIS OF THE TOTAL POPULATION

As indicated earlier, analysis of the entire population is possible with the inclusion of dummy variables which attempt to correct for the differing ship classes cited. This section uses the previously introduced dummy variable "escdumy", correcting the population as a **"homogeneous escort"** data sample of 88. A recall of those variables follows:

FFG...	0.6936
DD....	1.0159
DDG...	2.0161
CG....	3.0299

The analysis will proceed with a preliminary display of the impact of the dummy variables upon a simplistic equation, followed by a series of iterations which will stepwise remove explanatory variables.

```
The regression equation is
cost = 603109 - 2170 prop + 5816 cmd&s - 1250 aux

Predictor       Coef       Stdev    t-ratio
Constant      603109       94197       6.40
prop         -2169.9       259.2      -8.37
cmd&s         5815.8       732.0       7.95
aux          -1249.9       221.8      -5.63

s = 21272       R-sq = 72.2%     R-sq(adj) = 71.1%

Analysis of Variance

SOURCE       DF          SS          MS         F
Regression    3 91468021760 30489339904     67.38
Error        78 35294380032   452492064
Total        81 1.26762E+11

SOURCE       DF      SEQ SS
prop          1 38414573568
cmd&s         1 38685679616
aux           1 14367767552

Durbin-Watson statistic = 0.99
```

```
      6.0+
         -                            *
 residual-
         -
         -
      3.0+                        * = data point
         -                        # = # points
         -              *         + = >10 points
         -    **        3
         -     6     * 3 5                              2
      0.0+ -- +5 -- 3  5 + 2 ------------------------------
         -    5*    3  2 2                                  2
         -          3  *
         -                                            *
         -                                 4
     -3.0+
         -
          +---------+---------+---------+---------+---Ycost
        60000     90000    120000    150000    180000
```

Figure 4.14(a)
Fourth Iteration

```
The regression equation is
logcst = 6.47 - 0.00652 prop + 0.0179 cmd&s - 0.00388 aux

Predictor        Coef       Stdev    t-ratio
Constant       6.4655      0.3391      19.07
prop       -0.0065174   0.0009332      -6.98
cmd&s        0.017862    0.002635       6.78
aux        -0.0038788   0.0007984      -4.86

s = 0.07657     R-sq = 73.1%     R-sq(adj) = 72.0%

Analysis of Variance

SOURCE       DF         SS          MS         F
Regression    3    1.24145     0.41382     70.58
Error        78    0.45732     0.00586
Total        81    1.69878

SOURCE       DF     SEQ SS
prop          1    0.75438
cmd&s         1    0.34870
aux           1    0.13838

Durbin-Watson statistic = 0.94
```

```
     5.0+                         *
        -
residual-
        -
        -
     2.5+
        -
        -     **                *
        -      4      3         5
        -      2    * 3       3 3
     0.0+ --- 62 -- 2 * ----- 5 2 -----------------------
        -     33    * *       7                         2
        -     5*    3 *
        -     *     *                         2
        -           *                         2
    -2.5+
        -
        +---------+---------+---------+---------+---------+----Ycost
      4.80      4.90      5.00      5.10      5.2       5.3
```

Figure 4.14(b)
Fourth Iteration with Transformation

1. The Impact of the Homogeneous Escort Variable

As an indication of the dummy variable's impact on the population regression models, the variable is coupled with the explanatory total weight in the output cited as Figure 4.15. In this case, the t-ratio has loaded the independent variables' slope almost entirely upon the dummy variable.

In contrast with a prior simple regression (Figure 4.9(a)), a significantly different outcome results. Specifically, note that the explanatory variables' ability to predict Y has increased from 35.6% to 80.7%. Also, regression efficiency has improved, as witnessed by the four fold increase in the F statistic. Although not displayed, the log transformation of Y produces similar results when regressed with the correcting variable.

2. Multiple regression of the "Homogeneous Escorts"

The first iterations are displayed as Figures 4.16(a) and 4.16(b). MINITAB automatically removes total weight from the equations and the slopes corresponding with hull weight ("hull") are largely insignificant. Additionally, the affect of armament weight ("arm") is of little contribution. These items attest to the associated prior model findings, Figures 4.11(a) and 4.11(b). Note that standard errors are higher with the added variable.

The regression equation is
cost = 7403 - 5.16 swbtot + 121056 escdumy

Predictor	Coef	Stdev	t-ratio
Constant	7403	9666	0.77
swbtot	-5.163	3.286	-1.57
escdumy	121056	9204	13.15

s = 31389 R-sq = 81.1% R-sq(adj) = 80.7%

Analysis of Variance

SOURCE	DF	SS	MS	F
Regression	2	3.59328E+11	1.79664E+11	182.36
Error	85	83745439744	985240448	
Total	87	4.43073E+11		

SOURCE	DF	SEQ SS
swbtot	1	1.88895E+11
escdumy	1	1.70433E+11

Durbin-Watson statistic = 1.14

```
                                                    * = data point
                                                    # = # points
                                                    + = >10 points
         -    *
     5.0+           *
        -
residual-
        -                                                    *
        -
     2.5+
        -                                       *
        -
        -    *      *                                      2
        -    +      3
     0.0+ ---+------+-------------------------- * ---------------
        -    +      +                           2          *  *
        -    *                                                 *
        -
        -
    -2.5+
        +---------+---------+---------+---------+---Ycost
       100000    150000    200000    250000    300000
```

Figure 4.15
Impact of "Homogeneous Escort" Variable

Here, the output <u>without</u> transformation produces a model of similar regression efficiency and ability to predict Y as the log transformed counterpart. This element should be tracked throughout the population, as the ability of the model without transformation becomes first equivalent, then marginally more effective. This is evidenced by changes to the R-sq(adj) and F ratio components. Both residual plots are robust in their pattern of residual display and provided without further comment.

The second iteration of both models is given as Figures 4.17(a) and 4.17(b). Here, explanatory variables "swbtot", "hull" and "arm" have been removed prior to the regression. The benefits of removal of the associated degrees of freedom is marginal. The residual plots are similar to preceding displays.

The slope loading on the dummy variable is less than the explanatory "elec" and "aux" in the case without transformation. Note, the dummy variable remains robust for the regression with transformation. Stepwise, these removal candidates were regressed along with the dummy variable.

The completed results of the stepwise regression are displayed in Figures 4.18(a) and 4.18(b). In this final iteration, the slope loading of all weight explanatories exceeds a t-ratio of 2.0 and consequently, better models without degradation, are not available from this approach.

The regression equation is
cost = 407703 - 13 hull - 1457 prop + 1747 elec + 4191 cmd&s - 608 aux - 1286 out&f + 181 arm - 105472 escdumy

Predictor	Coef	Stdev	t-ratio
Constant	407703	134886	3.02
hull	-12.7	123.7	-0.10
prop	-1456.8	456.3	-3.19
elec	1747	1334	1.31
cmd&s	4190.9	876.6	4.78
aux	-607.8	283.8	-2.14
out&f	-1286.1	526.9	-2.44
arm	181.2	336.6	0.54
escdumy	-105472	60121	-1.75

s = 27917 R-sq = 86.1% R-sq(adj) = 84.7%

Analysis of Variance

SOURCE	DF	SS	MS	F
Regression	8	3.81505E+11	47688142848	61.19
Error	79	61567860736	779340032	
Total	87	4.43073E+11		

SOURCE	DF	SEQ SS	SOURCE	DF	SEQ SS
hull	1	1.65183E+11	prop	1	1.79540E+11
elec	1	7471985152	cmd&s	1	20017293312
aux	1	1302461952	out&f	1	5560605184
arm	1	31904370	escdumy	1	2398550528

Durbin-Watson statistic = 1.35

```
residual-
        -              *         *
        -
    3.5+
        -
        -                                *               *
        -
        -     *2*  3                                      *
    0.0+ ---  +58  +2 ---3 ----------    * ---------------
        -     224  3    26               2
        -                2
        -                    * = data point
        -                    # = # points                 *
   -3.5+                     + = >10 points
        -
        -                                                *
        -
        +--------+--------+--------+---------+-------Ycost
      60000   120000   180000   240000   300000
```

Figure 4.16(a)
Multiple Regression of All Explanatories

```
The regression equation is
logcst = 5.94 -0.000045 hull - 0.00482 prop + 0.00831 elec
+   0.0144 cmd&s - 0.00232 aux - 0.00508 out&f + 0.00122
arm - 0.617 escdumy

Predictor        Coef         Stdev     t-ratio
Constant       5.9381        0.3731       15.91
hull         -0.0000454    0.0003421      -0.13
prop         -0.004815     0.001262       -3.82
elec          0.008305     0.003690        2.25
cmd&s         0.014391     0.002425        5.93
aux          -0.0023159    0.0007850      -2.95
out&f        -0.005075     0.001458       -3.48
arm           0.0012249    0.0009311       1.32
escdumy      -0.6170       0.1663         -3.71
s = 0.07723      R-sq = 86.3%     R-sq(adj) = 85.0%

Analysis of Variance
SOURCE        DF          SS            MS           F
Regression     8     2.98022       0.37253       62.47
Error         79     0.47113       0.00596
Total         87     3.45135
SOURCE        DF       SEQ SS    SOURCE          DF       SEQ SS
hull           1      1.83261    prop             1      0.88164
elec           1      0.01544    cmd&s            1      0.06220
aux            1      0.01260    out&f            1      0.09333
arm            1      0.00032    escdumy          1      0.08207
Durbin-Watson statistic = 1.21
```

```
             -
    residual-              *
             -
             -
         3.5+                                   *
             -
             -
             -    * *  *                              *
             -    3 2  4   3 32        *                     *
         0.0+ -- 5 3 -6---4 + ---------3 --------------3 ---------
             -    6 2  4   *          25
             -    * *  2   *          2
             -
             -
        -3.5+                                                  *
             -
             -
             +---------+---------+---------+---------+----Ycost
          4.80      4.95      5.10      5.25      5.4     5.5
```

Figure 4.16(b)
First Iteration with Transformation

```
The regression equation is
cost = 382530 - 1491 prop + 1676 elec + 4115 cmd&s - 537
aux  - 1245 out&f - 91652 escdumy

Predictor        Coef        Stdev     t-ratio
Constant       382530       106349        3.60
swb2          -1491.2        324.5       -4.59
swb3           1675.8        821.1        2.04
swb4           4115.2        851.4        4.83
swb5           -536.5        246.3       -2.18
swb6          -1244.7        371.4       -3.35
escdumy        -91652        54222       -1.69

s = 27640        R-sq = 86.0%      R-sq(adj) = 85.0%

Analysis of Variance
SOURCE        DF           SS            MS          F
Regression     6  3.81190E+11   63531663360      83.16
Error         81  61883035648     763988096
Total         87  4.43073E+11
SOURCE        DF       SEQ SS
prop           1  1.08608E+11
elec           1  2.41591E+11
cmd&s          1  20003409920
aux            1     54581820
out&f          1   8749990912
escdumy        1   2182862848
Durbin-Watson statistic = 1.33
```

```
     6.0+
        -          *
residual-                    *                          *
        -
        -
     3.0+
        -                                *
        -
        -
        -   *3*   32
     0.0+ -- +46   + ----- 3 ---------- 2 ------------- *
        -   226   3      26             *
        -                2
        -
        -
    -3.0+
        -
         +---------+---------+---------+---------+-Ycost
     60000    120000    180000    240000    300000
```

Figure 4.17(a)
Second Iteration

```
The regression equation is
logcst = 5.75 - 0.00494 prop + 0.00816 elec + 0.0139 cmd&s
-  0.00183 aux - 0.00492 out&f - 0.524 escdumy

Predictor        Coef         Stdev     t-ratio
Constant       5.7541        0.2975       19.34
prop        -0.0049445    0.0009080       -5.45
elec         0.008155     0.002297         3.55
cmd&s        0.013938     0.002382         5.85
aux         -0.0018321    0.0006891       -2.66
out&f       -0.004916     0.001039        -4.73
escdumy     -0.5241       0.1517          -3.45

s = 0.07733      R-sq = 86.0%      R-sq(adj) = 84.9%

Analysis of Variance
SOURCE       DF          SS          MS          F
Regression    6     2.96697     0 49450      82.69
Error        81     0.48438     0.00598
Total        87     3.45135
SOURCE       DF      SEQ SS
prop          1     1.38527
elec          1     1.31058
cmd&s         1     0.06210
aux           1     0.00000
out&f         1     0.13765
escdumy       1     0.07137
Durbin-Watson statistic = 1.16
```

```
         -             *
         -
     5.0+
         -
residual-
         -                          *
         -
     2.5+                                           *
         -                                   *
         -   * *
         -     2  *    2                               *
         -   3    4  3 32        *         *
     0.0+ -- 4 3  2 --3 + ------ 2 ------- 2 ----------*
         -   6 2  2  *           3
         -   2 *  3  *        3  3
         -        *  *        *                        *
         -
         +---------+---------+---------+---------+----Ycost
       4.80      4.95      5.10      5.25      5.4      5.5
```

Figure 4.17(b)
Second Iteration with Transformation

Provided here is a slight decay of both models with slightly worse values for both R-sq(adj) and standard error statistics. Also, slope loading on the dummy variable in Figure 4.18(a) is again less than the weight explanatory variables which remain.

3. Conclusions from the population

The addition of the dummy variable corresponding to a factor correction of the data as "homogeneous escorts" has produced a better regression output from the population. Although significant gains were achieved in the statistical measures R-sq(adj) and F ratio, similar gains were not achieved in the standard error. Dependent variables without transformation were found to produce equations similar in performance to a logarithm transformation.

In the iterative technique, multiple regression has been performed to produce a resulting equation based upon 3 to 4 explanatory weight variables. The variables which remain in the cited regression equations correspond with weights of propulsion, command & surveillance and outfit & furnishing. These variables were more statistically significant in their ability to predict an outcome for the dependent variable.

```
The regression equation is
cost = 290717 - 1477 prop + 3811 cmd&s - 646 out&f - 10347
   escdumy

Predictor        Coef        Stdev    t-ratio
Constant       290717        73599       3.95
prop          -1477.1        327.1      -4.52
cmd&s          3810.5        822.4       4.63
out&f          -645.6        259.9      -2.48
escdumy       -103476        54266      -1.91

s = 28151       R-sq = 85.2%     R-sq(adj) = 84.4%

Analysis of Variance

SOURCE        DF          SS           MS           F
Regression     4 3.77296E+11  94323974144      119.02
Error         83 65777119232    792495424
Total         87 4.43073E+11

SOURCE        DF      SEQ SS
prop           1 1.08608E+11
cmd&s          1 2.61224E+11
out&f          1  4582369280
escdumy        1  2881501952
Durbin-Watson statistic = 1.29
```

```
     6.0+
        -           *                                   *
residual-                              * = data point
        -                              # = # points
        -                 *            + = >10 points
     3.0+
        -
        -                       *
        -
        -    3 5 *3*    *                                *
     0.0+--- 6 9 6+** - 3--------- * ----------------------
        -      + 2      7          2
        -               2                              **
        -
        -
    -3.0+                                                *
        -
        +---------+---------+---------+---------+---Ycost
      60000    120000    180000    240000    300000
```

Figure 4.18(a)
Final Iteration

```
The regression equation is
logcst = 5.68 - 0.00509 prop + 0.0138 cmd&s - 0.00234
out&f  -  0.533 escdumy

Predictor        Coef        Stdev    t-ratio
Constant       5.6846       0.2147      26.48
prop       -0.0050923    0.0009542      -5.34
cmd&s        0.013764     0.002399       5.74
out&f      -0.0023363    0.0007582      -3.08
escdumy       -0.5330       0.1583      -3.37

s = 0.08212     R-sq = 83.8%     R-sq(adj) = 83.0%

Analysis of Variance
SOURCE        DF         SS          MS         F
Regression     4    2.89159     0.72290    107.19
Error         83    0.55976     0.00674
Total         87    3.45135

SOURCE        DF     SEQ SS
prop           1    1.38527
cmd&s          1    1.37159
out&f          1    0.05829
escdumy        1    0.07644
Durbin-Watson statistic = 1.02
```

```
         -           *
     5.0+
        -
residual-
        -
        -
     2.5+                                                     *
        -                                          **
        -     *  *
        -     2  2  2
        -        3  4   32          *          3
     0.0+ --- 4 - 5 * - + ------- 3 ---------------------------
        -     *  8  *               5
        -     *  8  *              3                            *
        -        2                 *                            *
        -
    -2.5+
        +---------+---------+---------+---------+--Ycost
     4.80      4.95      5.10      5.25      5.4       5.5
```

Figure 4.18(b)
Final Iteration with Transformation

A summarizing statement upon the equation explaining shipbuilder's costs with the ESWBS weight variables for propulsion, command & surveillance and outfit & furnishing (without transformation) follows:

> The data reflect that ESWBS weight variables for propulsion, command & surveillance and outfit & furnishing will predict shipbuilders' cost of the escort vessel with an R-sq(adj) value of 84.4%. Further, within a confidence interval of 95%, actual costs greater than 46167 (or 1.64 times the standard error) of the model's predicted costs should be reviewed.

H. THE EFFECTS OF CONTRACT TYPE

As the majority of this thesis investigates the ability of component weights (only) to predict the associated costs, a non weight variable was sought. Within the limits of data provided the researcher, type of contract used in the ship construction, meets the above named requirement. Dummy variables corresponding to either "cost" type or "fixed price" were assimilated. The variables assigned to the data make no distinction of various incentive plans as sample size from the various ship types render further segregation unusable for analysis.

Transformation of the dependent variable contributed little to continued regression with dummy variables as evidenced by the preceding section. Consequently, the analysis continues without transformation Y.

As before, the analysis initiates with consideration of the dummy variable prior to stepwise regression.

1. Regression with type of contract considered

Figure 4.19 provides the output of dummy variables for contract type, regressed with total ESWBS weight.

```
The regression equation is
cost = 37979 + 12.1 swbtot + 164310 cntrk

Predictor        Coef         Stdev     t-ratio
Constant        37979          8417        4.51
swbtot         12.083         1.952        6.19
cntrk          164310          9589       17.13

s = 25911       R-sq = 87.1%      R-sq(adj) = 86.8%

Analysis of Variance
SOURCE        DF          SS            MS          F
Regression     2 3.86007E+11 1.93004E+11     287.48
Error         85 57065873408   671363200
Total         87 4.43073E+11

SOURCE        DF      SEQ SS
swbtot         1 1.88895E+11
cntrk          1 1.97112E+11
Durbin-Watson statistic = 1.42
```

```
     7.0+
        -
residual-            * = data point
        -            # = # points
        -            + = >10 points                        *
     3.5+
        -
        -
        -       *      *                                   **
        -      4+      5
     0.0+ ---- +7 ---- + --------------------------- * ----*2
        -      +3      +
        -
        -                                                   2
        -
    -3.5+                                                   *
        -
        +---------+---------+---------+---------+----Ycost
      50000    100000    150000    200000    250000
```

Figure 4.19
Consideration of Contract Type

The regression result provides striking results as to the significance of the non-weight variable. Contrasting this model (Figure 4.19) with the prior display of "homogeneous escort" versus total weight (Figure 4.15) establishes a statistically superior regression for this simple case.

2. **Multiple regression Contract type and Weights.**

The first iteration is given as Figure 4.20 wherein all ESWBS weights, total, and the two dummy variables (homogeneous escort and contract type) are regressed. Again, inclusion of the non-weight variable significantly improves the regression model as evidenced by the robust measures of standard error, R-sq(adj) and F ratio. Total weight drops automatically from the equation as in prior runs but, for the first time, the slope significance of the propulsion weight ("prop") has been reduced to minimal contribution.

The next iteration removes a degree of freedom associated with "prop" and in Figure 4.21 reflects a model with full slope loading of all variables. Further, the model makes substantial improvement upon the F statistic, with marginal gain to the predictive abilities of the explanatories. Although contribution is significant, the assumption of slope loading (arbitrarily selected as t-ratios of 2.0 and greater) is relaxed to further limit the degrees of freedom given from the multiple variables.

```
The regression equation is
cost = 122545 - 173 hull + 75 prop + 3905 elec + 1585
cmd&s -  575 aux - 1518 out&f - 1435 arm + 130346 escdumy
167764  cntrk

Predictor         Coef         Stdev     t-ratio
Constant        122545         80028        1.53
hull           -173.43         71.60       -2.42
prop              74.5         286.1        0.26
elec            3905.1         778.6        5.02
cmd&s           1585.5         539.3        2.94
aux             -574.6         161.8       -3.55
out&f          -1517.6         300.9       -5.04
arm            -1435.1         229.4       -6.26
escdumy         130346         38875        3.35
cntrk           167764         13056       12.85
s = 15914        R-sq = 95.5%      R-sq(adj) = 95.0%
Analysis of Variance
SOURCE          DF          SS            MS           F
Regression       9 4.23320E+11 47035588608     185.74
Error           78 19752720384   253240000
Total           87 4.43073E+11
SOURCE          DF      SEQ SS   SOURCE          DF       SEQ SS
hull             1 1.65183E+11   prop             1 1.79540E+11
elec             1  7471985152   cmd&s            1 20017293312
aux              1  1302461952   out&f            1   5560605184
arm              1    31904370   escdumy          1   2398550528
cntrk            1 41815142400   Durbin-Watson stat = 1.59
```

```
     7.0+
        -
residual-         * = data point
        -         # = # points
        -         + = >10 points
     3.5+                                          *
        -
        -     *                                       *          *
        -        *      *
        -     7  5 3 4  2                                        *
     0.0+ —— 8  4 4 7 *6 ————————————————————————————————————————
        -        + * 6 3                                    *
        -        2 *                               2      *       *
        -                                          *
        -                                                         *
    -3.5+                                                         *
        -
          +---------+---------+---------+---------+--Ycost
        60000    120000    180000    240000    300000
```

Figure 4.20
Multiple Regression with Contract Type

The regression equation is
cost = 136C59 - 160 hull + 3785 elec + 1675 cmd&s -582 aux - 1486 out&f - 1409 arm + 122694 escdumy + 166347 cntrk

Predictor	Coef	Stdev	t-ratio
Constant	136059	60577	2.25
hull	-160.46	51.15	-3.14
elec	3785.4	625.1	6.06
cmd&s	1674.8	413.5	4.05
aux	-581.6	158.5	-3.67
out&f	-1485.8	273.4	-5.43
arm	-1409.5	206.0	-6.84
escdumy	122694	25312	4.85
cntrk	166347	11799	14.10

s = 15819   R-sq = 95.5%   R-sq(adj) = 95.1%

Analysis of Variance

SOURCE	DF	SS	MS	F
Regression	8	4.23303E+11	52912889856	211.44
Error	79	19769907200	250251984	
Total	87	4.43073E+11		

SOURCE	DF	SEQ SS	SOURCE	DF	SEQ SS
hull	1	1.65183E+11	elec	1	1.80431E+11
cmd&s	1	7539058688	aux	1	2625996032
out&f	1	17433651200	arm	1	8827609
escdumy	1	339138848	cntrk	1	49743052800

Durbin-Watson statistic = 1.63

```
    7.0+
        -      * = data points                       *
residual-      # = # points
        -      + = >10 points
        -
     3.5+                                     *
        -
        -     *                                  *
        -        *      *
        -     7  5 332  2
     0.0+ --  8  4 4 +  6  -------------------------------
        -        9 * 2 4                              *    *
        -        3 *                          2   *
        -                                     *            *
        -
    -3.5+
        -
        -+-------+---------+---------+---------+-----Ycost
       60000    120000    180000    240000    300000
```

Figure 4.21
Second Iteration with Contract Type

In a stepwise procedure, the variables were omitted based upon their contribution until significant decay of the model ensued. The resultant equation is provided in Figure 4.22.

From Figure 4.22, three ESWBS weights remain in the model with the two dummy variables. The weights correspond with electric plant, outfit & furnishings and armament. Slope loading is robust and produces an entirely different model than prior editions. Note the marginal compromise of the standard error and R-sq(adj) measures.

3. Conclusions of the section

The inclusion of the non-weight dummy variable representing contract type has contributed significantly to the predictive ability of component weights.

In the iterative technique, multiple regression has been performed to produce a resulting equation based upon dummy variables (corresponding to contract type and escort), with 3 explanatory weight variables. The weight variables which remain in the cited regression equations coincide with weights of electric plant, outfit & furnishings, and armament. These variables were more statistically significant in their ability to predict an outcome for the dependent variable.

A summarizing statement upon the equation explaining shipbuilder's costs with the ESWBS weight variables for electric plant, outfit & furnishings and armament follows:

The data reflect that ESWBS weight variables for electric plant, outfit & furnishing, and armament will predict shipbuilders' cost of the escort vessel with an R-sq(adj) value of 93.7%. Further, within a confidence interval of 95%, actual costs greater than 29475 (or 1.64 times the standard error) of the model's predicted costs should be reviewed.

```
The regression equation is
cost = - 29949 + 1308 elec - 400 out&f - 1608 arm + 178211
escdumy  + 171068 cntrk

Predictor        Coef        Stdev    t-ratio
Constant       -29949        16413      -1.82
elec           1307.6        350.1       3.74
out&f          -399.8        174.8      -2.29
arm           -1607.7        211.8      -7.59
escdumy        178211        20286       8.79
cntrk          171068        13186      12.97
s = 17973       R-sq = 94.0%     R-sq(adj) = 93.7%

Analysis of Variance

SOURCE       DF           SS          MS         F
Regression    5  4.16585E+11 83317055488    257.93
Error        82  26487740416   323021216
Total        87  4.43073E+11

SOURCE       DF       SEQ SS
elec          1  2.74461E+11
out&f         1  31453124608
arm           1  43897966592
escdumy       1  12402840576
cntrk         1  54369865728

Durbin-Watson statistic = 1.75
```

```
     6.0+
        -      * = data point
residual-      # = # points
        -      + = >10 points
        -
     3.0+                                    *
        -                                   **
        -               *
        -      **3
        -       27      5
     0.0+      834     +3                    *
        -      737     +
        -        *                                       *
        -                                    2
        -                                    *          *
    -3.0+                                                *
        -
        +---------+---------+---------+---------+---------+----Ycost
      60000    120000    180000    240000    300000
```

Figure 4.22
Final Iteration with Contract type

V. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

The results of the analysis performed in this study indicate that the relationship between cost and weight of the surface escort will portend itself to linear regression techniques. Provided with the more robust equations are summary statements, of limited utility as a reference "check" of future escort cost estimates. Although statistically significant, the accuracies achieved by these models will not provide a point estimate of the quality demanded in the budgetary input.

Multiple regression equations of statistical significance were derived using builders´ cost as the dependent variables and component weights as the explanatory variables. Statistical significance was enhanced in the various models by the inclusion of dummy variables which attempted to correct the population as homogeneous escorts rather than specific, individual ships drawn from classes. Used within the analysis is a "escort" correction factor derived from a weighted average technique and applied to the population. Statistical significance was also improved by the inclusion of a non-weight dummy variable which reflected the type of contract under which the escort ship was built.

Normalization of the population was best achieved through the removal of outliers from the data base. A subsequent logarithmic transformation of the dependent variables provided the best symmetrical display of the data. Although this transformation does provide additional regression accuracy in some of the more simplistic models provided, the affects of the transformation diminish with higher order models and those which include dummy variables. Dummy variables were required in the regression of the entire population in order to improve regression accuracy.

The data cited are impacted by artificialities which affect normalization and linear fit of the population. These artificialities are: (1) the costs cited are actual return costs rather than the estimates of costs upon which the relationship was initially developed; (2) the weights cited are actual weights which are the end product of inclining experiments and/or delivery weight reports of baseline vessels; (3) a hull by hull accounting of the component weights was not available to the researcher. Consequently, baseline weights were applied to individual hulls on the assumption that variance among those vessels (within the baseline) would be minimal. Although the data were the best products available at the time of the research, the impact of these artificialities upon the results of the study are unknown.

The cost estimating procedures of varying agencies of the US Navy all exploit the relationship between cost and weight. A brief description of those methods is provided in the study.

B. RECOMMENDATIONS

This study suggests that regression analysis may produce estimation models which are useful to assess the credence of other techniques and shipbuilder cost estimates. Consequently, further study is recommended to more fully investigate this premise. Should the need for follow-on research be recognized, the author recommends that the population be expanded to included all surface vessels. Additionally, the potential utility of adding non-weight variables such as contract type or shipbuilder should be investigated.

As one of the limitations of the study is the data base itself, it follows that one recommendation would be to enhance future data elements.

The availability of original cost estimates may have enhanced this specific study. This stated, the author recognizes that the utility of retaining a running file of estimates is of marginal value toward other applications (and is certainly not without a "cost" unto itself). In the author's opinion however, such may not be the case regarding weight estimation data, which indeed would have enhanced the analysis. Although the NAVSEA cost estimation branch currently uses only the specific weight accountings of vessels under cost review, data exists within NAVSEA (of precision, and for the complete population of Naval vessels) that is of benefit to the 017 office. Cost estimation branch usage of this data will be the final recommendation.

It is recognized that the models provided in this thesis are general and basic emulations of a complex process utilizing measures more sophisticated than costs as a simple function of weights. However, the strong statistical significance of this relationship is easily and cost effectively captured through the power of regression. Therefore, the author recommends that the NAVSEA 017 be provided with statistical software packages in mainframe or microcomputer version for this purpose. Further, it is felt that the estimation branch with existing assets, could investigate models (such as contained within this thesis) as an additional and rapid avenue of cost validation.

Currently, the NAVSEA estimation branch does not normally apply statistical software packages (such as MINITAB) to their routine. Statistical work for that office is either conducted <u>externally</u> or on the statistical functions of spreadsheet programs. The author's opinion is that the statistical applications of spreadsheet software are insufficient for the potential applications to that office, that would be offered by existing packages (e.g., MINITAB, SSPSX, and STATGRAPHICS).

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APPENDIX

SWBS Description	Ship A	Ship B	Ship C	Ship D
		Wt Tons		
1 Hull Structure	3550	3631	3498	3505
2 Propulsion	725	710	713	713
3 Electric Plant	383	375	374	376
4 Command & Survel.	471	478	470	472
5 Auxiliary Systems	981	965	1013	1015
6 Outfit & Furn.	600	613	586	590
7 Armament	370	361	359	360
Total Ltship:	7080	7133	7013	7031

SWBS Description	Ship E	Ship F	Ship G
		Wt Tons	
1 Hull Structure	3320	3309	3316
2 Propulsion	714	711	712
3 Electric Plant	376	381	386
4 Command & Surveillance	477	481	488
5 Auxiliary Systems	973	983	987
6 Outfit & Furnishings	617	614	597
7 Armament	425	427	424
Total Ltship:	6902	6906	6910

SWBS Description	Ship H	Ship I	Ship J
		Wt Tons	
1 Hull Structure	1255	1251	1267
2 Propulsion	288	288	288
3 Electric Plant	195	197	198
4 Command & Surveillance	133	125	129
5 Auxiliary Systems	495	496	530
6 Outfit & Furnishings	317	319	323
7 Armament	95	96	97
Total Ltship:	2778	2772	2832

Ship Baseline Class SWBS Descriptions

SWBS Description	Ship K	Ship L
	Wt Tons	
1 Hull Structure	1364	1368
2 Propulsion	290	292
3 Electric Plant	210	216
4 Command & Surveillance	131	137
5 Auxiliary Systems	533	539
6 Outfit & Furnishings	331	341
7 Armament	98	99
Total Ltship:	2957	2992

SWBS Description	Ship M	Ship N	Ship O	Ship P
		Wt Tons		
1 Hull Structure	3107	3076	3076	3075
2 Propulsion	755	762	762	762
3 Electric Plant	277	285	285	285
4 Command & Surveillance	356	357	356	356
5 Auxiliary Systems	743	736	737	736
6 Outfit & Furnishings	440	478	479	479
7 Armament	152	154	154	154
Total Ltship:	5830	5848	5849	5847

SWBS Description	Ship Q	Ship R	Ship S	Ship T
		Wt Tons		
1 Hull Structure	3075	3075	3488	3110
2 Propulsion	762	762	750	772
3 Electric Plant	285	285	342	288
4 Command & Surveillance	356	356	414	384
5 Auxiliary Systems	736	736	936	771
6 Outfit & Furnishings	478	478	515	491
7 Armament	154	154	313	179
Total Ltship:	5846	5846	6758	5995

Ship Baseline Class SWBS Descriptions (continued)

COSTS, DATA CORRECTORS & DUMMY VARIABLES

ROW	cost	mid-date	dfltr	escdumy	cntrk
1	240585	4.75	1.2899	0.6940	1
2	82133	1.78	1.4512	0.6940	0
3	58714	2.79	1.6185	0.6940	0
4	63948	1.82	1.9010	0.6940	0
5	90024	2.83	2.1425	0.6940	0
6	86250	1.77	1.3680	0.6940	0
7	82409	1.78	1.4512	0.6940	0
8	67270	1.78	1.4512	0.6940	0
9	69465	2.78	1.4889	0.6940	0
10	61235	2.78	1.4889	0.6940	0
11	67923	3.78	1.5202	0.6940	0
12	57446	3.78	1.5202	0.6940	0
13	63691	3.78	1.5202	0.6940	0
14	70081	2.79	1.6185	0.6940	0
15	71141	1.79	1.5860	0.6940	0
16	65360	1.79	1.5860	0.6940	0
17	68269	2.79	1.6185	0.6940	0
18	68124	2.79	1.6185	0.6940	0
19	65957	3.79	1.6512	0.6940	0
20	71635	2.79	1.6185	0.6940	0
21	61133	2.80	1.7646	0.6940	0
22	62278	1.80	1.7194	0.6940	0
23	55562	1.80	1.7194	0.6940	0
24	59415	3.80	1.8024	0.6940	0
25	60183	2.80	1.7646	0.6940	0
26	53367	1.80	1.7194	0.6940	0
27	59060	3.80	1.8024	0.6940	0
28	86612	2.80	1.7646	0.6940	0
29	84828	1.81	1.9001	0.6940	0
30	84879	2.81	1.9303	0.6940	0
31	84470	2.81	1.9303	0.6940	0
32	66150	2.81	1.9303	0.6940	0
33	76952	3.81	1.9770	0.6940	0
34	76243	3.81	1.9770	0.6940	0
35	64180	3.81	1.9770	0.6940	0
36	95438	2.81	1.9303	0.6940	0
37	69818	2.82	2.0677	0.6940	0
38	60325	1.82	2.0398	0.6940	0
39	70665	2.82	2.0677	0.6940	0
40	83601	2.82	2.0677	0.6940	0
41	83870	1.83	2.1287	0.6940	0
42	96804	1.83	2.1287	0.6940	0
43	101450	2.83	2.1425	0.6940	0
44	71829	2.83	2.1425	0.6940	0

COSTS, DATA CORRECTORS & DUMMY VARIABLES (continued)

ROW	costs	mid-date	dfltr	escdumy	cntrk
45	94543	2.83	2.1425	0.6940	0
46	74952	4.83	2.1821	0.6940	0
47	90657	3.83	2.1589	0.6940	0
48	92679	3.83	2.1589	0.6940	0
49	140971	4.72	1.0000	1.1300	0
50	108540	1.75	1.2288	1.1300	0
51	106709	2.75	1.2444	1.1300	0
52	100058	3.76	1.3289	1.1300	0
53	98366	4.76	1.3499	1.1300	0
54	98366	4.76	1.3499	1.1300	0
55	273615	3.79	1.6512	2.0161	1
56	266422	2.81	1.9303	1.1300	1
57	128921	1.73	1.0295	1.1300	0
58	128906	1.73	1.0295	1.1300	0
59	125499	3.73	1.0653	1.1300	0
60	119777	1.74	1.1072	1.1300	0
61	119777	1.74	1.1072	1.1300	0
62	116870	2.74	1.1348	1.1300	0
63	116894	2.74	1.1348	1.1300	0
64	116911	2.74	1.1348	1.1300	0
65	108075	1.75	1.2288	1.1300	0
66	108064	1.75	1.2288	1.1300	0
67	108066	1.75	1.2288	1.1300	0
68	108060	1.75	1.2288	1.1300	0
69	108089	1.75	1.2288	1.1300	0
70	102138	2.76	1.3130	1.1300	0
71	101131	2.76	1.3130	1.1300	0
72	100058	3.76	1.3289	1.1300	0
73	98394	4.76	1.3499	1.1300	0
74	96486	2.77	1.3901	1.1300	0
75	94182	3.77	1.4103	1.1300	0
76	94183	3.77	1.4103	1.1300	0
77	94349	3.77	1.4103	1.1300	0
78	94183	3.77	1.4103	1.1300	0
79	92744	4.77	1.4324	1.1300	0
80	93076	4.77	1.4324	1.1300	0
81	206602	4.79	1.6805	2.0161	1
82	202306	4.79	1.6805	2.0161	1
83	212239	1.80	1.7194	2.0161	1
84	442949	4.80	1.8513	3.0300	1
85	325654	2.82	2.0677	3.0300	1
86	325611	3.83	2.1589	3.0300	1
87	311651	4.83	2.1821	3.0300	1
88	274994	2.84	2.2233	3.0300	1

ESWBS WEIGHT DATA

ROW	swbtot	hull	prop	elec	cmd&s	aux	out&f	arm
1	2778	1255	288	195	133	495	317	95
2	2772	1251	288	197	125	496	319	96
3	2832	1267	288	198	129	530	323	97
4	2957	1364	290	210	131	533	331	98
5	2992	1368	292	216	137	539	341	99
6	2772	1251	288	197	125	496	319	96
7	2772	1251	288	197	125	496	319	96
8	2772	1251	288	197	125	496	319	96
9	2772	1251	288	197	125	496	319	96
10	2772	1251	288	197	125	496	319	96
11	2772	1251	288	197	125	496	319	96
12	2772	1251	288	197	125	496	319	96
13	2772	1251	288	197	125	496	319	96
14	2832	1267	288	198	129	530	323	97
15	2832	1267	288	198	129	530	323	97
16	2832	1267	288	198	129	530	323	97
17	2832	1267	288	198	129	530	323	97
18	2832	1267	288	198	129	530	323	97
19	2832	1267	288	198	129	530	323	97
20	2832	1267	288	198	129	530	323	97
21	2832	1267	288	198	129	530	323	97
22	2832	1267	288	198	129	530	323	97
23	2832	1267	288	198	129	530	323	97
24	2832	1267	288	198	129	530	323	97
25	2832	1267	288	198	129	530	323	97
26	2832	1267	288	198	129	530	323	97
27	2832	1267	288	198	129	530	323	97
28	2832	1267	288	198	129	530	323	97
29	2957	1364	290	210	131	533	331	98
30	2957	1364	290	210	131	533	331	98
31	2957	1364	290	210	131	533	331	98
32	2957	1364	290	210	131	533	331	98
33	2957	1364	290	210	131	533	331	98
34	2957	1364	290	210	131	533	331	98
35	2957	1364	290	210	131	533	331	98
36	2957	1364	290	210	131	533	331	98
37	2957	1364	290	210	131	533	331	98
38	2957	1364	290	210	131	533	331	98
39	2957	1364	290	210	131	533	331	98
40	2957	1364	290	210	131	533	331	98
41	2992	1368	292	216	137	539	341	99
42	2992	1368	292	216	137	539	341	99
43	2992	1368	292	216	137	539	341	99
44	2992	1368	292	216	137	539	341	99

ESWBS WEIGHT DATA (continued)

ROW	swbtot	hull	prop	elec	cmd&s	aux	out&f	arm
45	2992	1368	292	216	137	539	341	99
46	2992	1368	292	216	137	539	341	99
47	2992	1368	292	216	137	539	341	99
48	2992	1368	292	216	137	539	341	99
49	5830	3107	755	277	356	743	440	152
50	5848	3076	762	285	357	736	478	154
51	5849	3076	762	285	356	737	479	154
52	5847	3075	762	285	356	736	479	154
53	5846	3075	762	285	356	736	478	154
54	5846	3075	762	285	356	736	478	154
55	6758	3488	750	342	414	936	515	313
56	5995	3110	772	288	384	771	491	179
57	5830	3107	755	277	356	743	440	152
58	5830	3107	755	277	356	743	440	152
59	5830	3107	755	277	356	743	440	152
60	5830	3107	755	277	356	743	440	152
61	5830	3107	755	277	356	743	440	152
62	5830	3107	755	277	356	743	440	152
63	5830	3107	755	277	356	743	440	152
64	5830	3107	755	277	356	743	440	152
65	5848	3076	762	285	357	736	478	154
66	5849	3076	762	285	356	737	479	154
67	5849	3076	762	285	356	737	479	154
68	5849	3076	762	285	365	737	479	154
69	5849	3076	762	285	365	737	479	154
70	5849	3076	762	285	365	737	479	154
71	5849	3076	762	285	365	737	479	154
72	5847	3075	762	285	356	736	479	154
73	5846	3075	762	285	356	736	479	154
74	5846	3075	762	285	356	736	479	154
75	5846	3075	762	285	356	736	479	154
76	5846	3075	762	285	356	736	479	154
77	5846	3075	762	285	356	736	479	154
78	5846	3075	762	285	356	736	479	154
79	5846	3075	762	285	356	736	479	154
80	5846	3075	762	285	356	736	479	154
81	6758	3488	750	342	414	936	515	313
82	6758	3488	750	342	414	936	515	313
83	6758	3488	750	342	414	936	515	313
84	7080	3550	725	383	471	981	600	370
85	7133	3631	710	375	478	965	613	361
86	7013	3498	713	374	470	1013	586	359
87	7031	3505	713	376	472	1015	590	360
88	6902	3320	714	376	477	973	617	425

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9.	Defense Logistics Studies Information Exchange U.S. Army Logistics Management Center, Fort Lee, Virginia 23801-0000	1